

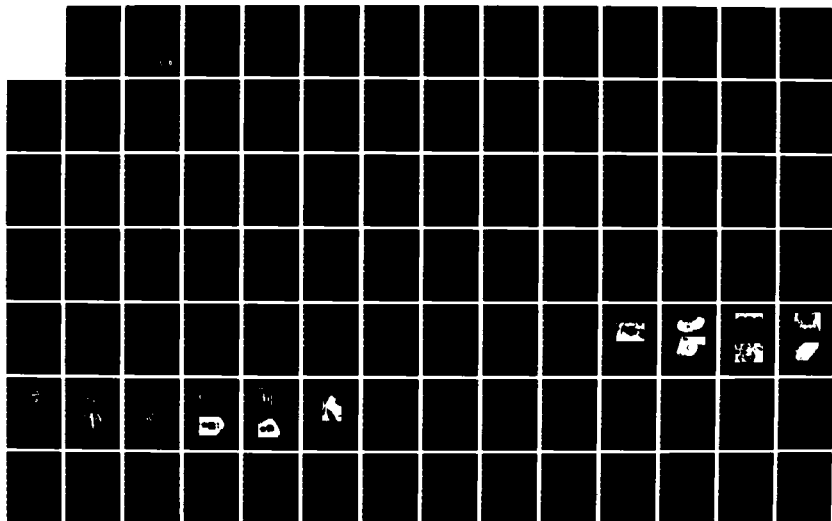
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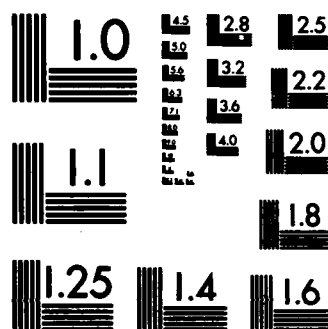
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**SENSIBILITY OF TEETH HAVING BASED VERSUS NON-BASED
AMALGAM RESTORATIONS: A CLINICAL STUDY**

by

Brock C. Miller, D.D.S.

**A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science
in Restorative Dentistry (Operative) at the
Horace H. Rackham School of Graduate Studies
of The University of Michigan
Ann Arbor, Michigan**

April 1983

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Assistant Professor Leopold H. Klausner**

DEDICATION

To Dr. Bill Paetz, friend and counselor,
who introduced me to the only knowledge worthy of the name:
that of our Lord Jesus.

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INTRODUCTION

Postoperative thermal sensitivity under amalgam restorations can be a bothersome problem for a dental patient. Many different approaches have been introduced in an attempt to prevent or to treat the problem. None have been found to be completely satisfactory.

One traditional procedure used in dentistry has been to place a cement base underneath an amalgam restoration to provide insulation for protection from thermal sensitivity when the prepared cavity is deep. Many dentists have supported this concept even though it has not been experimentally verified in a clinical setting under controlled conditions. Evidence is available in the literature which indicates that insulating bases may be ineffectual in preventing postoperative thermal sensitivity.

→ The purpose of this study is to compare in human subjects the sensibility to cold water of teeth having amalgam restorations with ideal zinc phosphate cement bases with amalgam restorations having no bases. The significance of the research will be to establish the clinical effectiveness of bases of "ideal" depth under amalgam restorations as a protection against a cold stimulus. ↗

REVIEW OF THE LITERATURE

Bases Under Amalgam: History

The use of bases under amalgam restorations was not described in the literature until 1868.(1) For many dental educators of the nineteenth century amalgam was considered to be a vile pernicious material(2). As such, techniques involving its placement were not very carefully described by those who wished to condemn it. Those articles which advocated the use of amalgam in the early literature did not mention the use of any base material under amalgam.

While it is possible that some individuals used protective linings under amalgam, the practice was not widespread. Certainly, pulp protection was not unknown. Harrower (3), in 1886, stated that a protective layer of varnish was used under gold fillings as early as 1846 but that the practice never became generally accepted by the dental profession. In 1886, Reese(4) related that the placement of a protective lining under amalgam was not used in ordinary dental practice. Noel(5), in 1882, described the use of "Hill's stopping" (a gutta percha product) as thermal insulation under amalgam as a new idea, at least for him.

A possible explanation for the resistance to the use of bases was offered by Bronson(6) in 1880. He stated that "comparatively few years ago, a filling composed of more than one material was considered to be intrinsically

defective and the insertion of such was held as unprofessional practice...."

Later, objections to the use of dissimilar materials disappeared. Dentists found other reasons for not placing bases. Reed(7), in 1904, wrote this about bases: "quite a few have written on the subject but it does not seem to be very generally practiced....They say, 'Won't the cement dissolve out at the margin' or, 'Will it hold the fillings? Is the anchorage sufficient?'"

Interestingly, since their inception, cements have been associated with amalgam. As early as 1863, Rymer(8) described using a mixture of two parts osteoplastic (a zinc oxychloride cement) and one part amalgam for a final restoration. Parker(9), in 1890, advocated the use of a similar mix of zinc phosphate cement and amalgam. He claimed that the final restoration had the adhesiveness of the cement and the durability of the amalgam. The use of such mixtures generally disappeared by the 1920's.

Although bases were not described in the amalgam literature prior to 1868, they were used under gold fillings at earlier dates. The 1850 edition of Harris' Principles and Practice of Dental Surgery(2) mentioned that insulation could be used under gold restorations to prevent thermal hypersensitivity in teeth with very deep caries. The materials suggested were asbestos, cork, oiled silk, and gutta percha. Harris(2), in the 1859 edition of his

textbook "A System of Dental Surgery", wrote that pulp capping could be done by means of covering the deep cavity preparation with ivory, quillhorn, or gold foil folded over 6-8 times. He recommended, however, that a gutta percha temporary, placed for several months was the treatment of choice in cases of thermal sensitivity. The replacement of the gutta percha temporary by gold at the later date did not include the placement of any insulation under the restoration. Tomes thought that amalgam was a temporary material only. No insulation was mentioned as ever being placed underneath his amalgam temporaries.

In 1868, "Hills soft stopping" was recommended for use as a palliative underneath amalgam when deep caries was present(1). Lewis(11), in 1870, wrote about the necessity of a cement to be placed in deep cavities to protect the pulp from condensation pressures during the placement of amalgam restorations. He made no mention of the need for thermal protection under amalgam.

Recommendations for the use of cements under gold foil restorations began appearing in the textbooks in the 1870's. Tomes(12) in 1873, Harris(13) in 1876, and Taft(14) in 1877 recommended the use of zinc oxychloride insulation before filling with gold foil. The 1887 edition of Tomes' textbook(15) recommended using zinc phosphate cement under gold restorations and zinc oxide and eugenol cement if the remaining dentin was very thin.

During this period amalgam was becoming more acceptable to the dental educators. In 1859, Harbert(16) wrote that amalgam should be used in very deep or very large cavities when gold foil was unsuitable. The Harris textbook of 1876(13) finally conceded that amalgam could be used on some teeth--but only those "so far gone that nothing else will anser." By 1892, the Harris textbook(17) ceased reviling amalgam and even recommended that Hill's stopping or zinc oxyphosphate cement be used under amalgam in deep cavities.

The textbooks cited previously never really stressed the use of a protective liner under metallic restorations. Usually the material related to thermal protection was an aside note and not mentioned as part of a normal cavity preparation procedure.

However, the use of cement liners under amalgam continued to be publicized until it became an accepted dental procedure(18). Increased interest in the physical and biological properties of cements developed in the 1950's and has led to a veritable explosion in the number of articles dealing with the topics of microleakage, solubility, thermal properties, strength, and the biologic compatability of cements.

Bases Under Amalgam: Terminology

Harrower(3), in 1886, was the first to use the term "base" for a cement liner underneath an amalgam restoration.

The use of the term did not become common until the mid-twentieth century. Prior to that all material used underneath metallic restorations were referred to as "cavity linings," "cavity liners," or more simply, "linings," and "liners." These included such diverse materials as cements, varnishes, asbestos, gutta percha, paper, cork, and oiled silk. (2,3,19,20)

Since then the materials used have been grouped into several different categories by function and type. The terms "cement base," intermediary base," "cavity varnishes," and "cavity liners" are currently being used. However, the term "base" itself is quite flexible and has been used to apply to all of these terms. Authors have disagreed about the distinctions between the various categories. Some semantic confusion has resulted.

Charbeneau et al.(21) and Craig(22) do not arrange cavity liners and varnishes in separate categories. Rather, cavity varnishes, cavity suspensions, and aqueous calcium hydroxide suspensions are all considered to be cavity liners. Others(23,24) are careful to distinguish between cavity liners and varnishes. Going(23) writes that "the term cavity liners should be reserved for aqueous or volatile organic liquid suspensions or dispersions of zinc oxide or calcium hydroxide...." He places varnishes into a separate category.

Likewise, disagreements exist as to what constitutes a

"base" and what does not. Piperno et al.(25) distinguished between a calcium hydroxide cement cavity liner and a cement base of zinc phosphate. Placement of the calcium hydroxide cement liner was not considered to qualify as placing a base. Farah(26), in contrast, called the same calcium hydroxide cement a base since it functioned as one, i.e. it was the base or support upon which the amalgam rested.

Charbeneau et al.(21) went one step further and distinguished between intermediary bases and cement bases. An intermediary base functions like a cavity liner in that it can protect the dentin and/or bring some therapeutic benefit to the tooth. However, it is thicker than a cavity liner. Whether the term "intermediary" refers to the position between the dentin and a potentially irritating cement base above or if it refers to the base's intermediate strength properties is not clear. Zinc oxide-eugenol and calcium hydroxide cements are given as examples of intermediary bases.

Continuing, Charbeneau et al.(21) defined cement bases as those having adequate strength when used in bulk to support occlusal function. They stated that zinc phosphate, reinforced zinc oxide-eugenol, and zinc polycarboxylate cements qualify as cement bases. In contrast, Going(23) described zinc phosphate, zinc oxide-eugenol, and calcium hydroxide cement as all being "intermediary base materials." Craig(22) wrote that cavity varnish can qualify as an

intermediary base if it is used over dentin to protect it from a base of zinc phosphate.

Powers(24) placed bases into two categories--low strength bases and high strength bases. He lists calcium hydroxide and zinc oxide-eugenol cements as being low strength bases because they have about one-twentieth of the strength of high strength bases. High strength bases include zinc phosphate, reinforced zinc oxide-eugenol, and polycarboxylate cements.

Bases Under Amalgam: Function

Cement bases have been called upon to protect the tooth from thermal hypersensitivity, thermal trauma, condensation pressures, toxic ingredients of other restorative materials, galvanic shock, and from microleakage. In addition, some bases have therapeutic effects while others are selected because of their ability to support amalgam.

Studies have shown that the thickness of a base was probably the most important parameter of thermal transfer(27,28). However, Peters and Augsburger(29) conclude from their laboratory study on bases, that 0.5 to 0.6mm of base is a sufficient thickness. The authors claimed no significant increase in thermal protection resulted if the bases were thicker than 0.6mm. In general, the cement base materials currently in use have good insulating properties(22). These include zinc phosphate, zinc

oxide-eugenol, polycarboxylate, and calcium hydroxide cements.

The strength properties of cements are also of concern. Lewis(11), in 1870, wrote that the pulp in deep cavities should be protected from condensation pressure. He recommended placement of osteoplastic (a zinc oxychloride cement) to prevent flexure of the pulpal floor and subsequent damage to the pulp. The ability of a cement to support condensation of amalgam without displacement and to support the amalgam during function have also been studied. As expected, those bases having greater compressive strength provide more support than the weaker ones. Powers, Farah, and Craig(30) found that the supporting ability of a base depends on its modulus of elasticity. The higher the modulus of elasticity the less likely a base is to fracture under load. While Chong, Swartz, and Phillips(31) found that some calcium hydroxide and non-reinforced zinc oxide-eugenol cements had sufficient strength to resist amalgam condensation pressures, Farah et al.(26) found calcium hydroxide cement was too weak to support amalgam in function. They recommend that the "thickness of a base with a low modulus of elasticity, such as calcium hydroxide, should not exceed 0.5mm." Zinc phosphate and polycarboxylate cements were found to have adequate compressive strengths at increased thicknesses.

Zinc oxide-eugenol and calcium hydroxide cements are

thought to have therapeutic benefits. Both have been used for direct and indirect pulp caps to stimulate reparative dentin formation. Several animal studies have been conducted to investigate this phenomena. Heys et al.(32) found that the calcium hydroxide preparations are more effective than zinc oxide eugenol at stimulating reparative dentin formation when used as liners. Studies of direct pulp caps have found that little reparative dentin forms under zinc oxide-eugenol(33,36). Zinc oxide-eugenol is thought to produce milder pulpal responses(34).

With regard to indirect pulp capping, both zinc oxide-eugenol and calcium hydroxide cements may have antibacterial properties. Fairbourn, Charbeneau, and Loesche(35) found that indirect pulp capping with those compounds resulted in a significant decrease in bacteria in deep carious lesions. Both compounds were equally effective.

In addition, zinc oxide-eugenol cement is thought to have an obtundant effect on the teeth. The eugenol has topical anesthetic properties. Some suggest using a zinc oxide-eugenol base when given a history of patient discomfort. (21)

Protecting the teeth from galvanism, toxic ingredients, and microleakage are dependent on the sealing properties of the cements. All cements shrink during setting and are thus subject to microleakage. (23) Zinc oxide-eugenol and zinc

phosphate cement bases have been judged as ineffective sealers in isotope penetration studies. (36,37) However, Going(23) wrote that cement bases "serve to mechanically block the gross ingress of injurious fluids and bacterial toxins incident to microleakage." Since zinc phosphate liquid is in itself irritating to the pulp, a varnish or cavity liner should first be placed under it. (21) Phillips, Phillips, and Schnell(38) wrote that both zinc phosphate and zinc oxide-eugenol cements are effective electrical insulators but that calcium hydroxide is not. However, they found that under normal oral conditions, microleakage allows the galvanic current to bypass base materials. Yates, Murray, and Hembree(39) found, in an isotope penetration study, that Copalite used in conjunction with the various cement bases and amalgam effectively eliminated microleakage. Other liners showed moderate to gross leakage with any of the bases.

Dentinal Sensitivity

Innervation of Dentin

The sensitivity of dentin would be easily explainable if nerve fibers could be demonstrated to exist throughout dentin. In 1866, Cutler(40) suggested that the nerves might accompany the odontoblastic processes in the dentinal tubules. However, innervation throughout has yet to be

demonstrated.

If sensory nerve endings were present throughout dentin, it is thought that they should be reactive to the same chemical substances that provoke pain in other nerve endings. The absence of such reactivity has led many to search for alternative explanations for dentinal sensitivity.(41) Potassium chloride, acetylcholine, 5-hydroxytryptamine, and histamine do not cause pain when applied to exposed dentin but will when applied to the pulp.(42,43)

Recent studies using autoradiography have confirmed earlier light microscopic and electron microscopic studies that, while sensory nerve fibers are indeed found in dentin, their penetration is very limited in depth.(44,45) Byers and Matthews(45) labeled the sensory nerve endings in cat teeth by axonal transport of radioactive protein. The left trigeminal ganglions of the cats were injected with the isotopes ^3H -proline and ^3H -leucine. The cats were sacrificed after 24 hours and the teeth were examined by autoradiography to determine the position of the sensory nerve endings. Labeled axons were found in most ipsilateral teeth. The axons ended in the odontoblastic layer, predentin, and as far as 150 micrometers into the dentinal tubules. These measurements agree well with the measurements of other studies.(46,47)

The innervation of the predentin and dentin does not

appear to be uniformly distributed throughout the tooth.(48,49) Lilja(48), divided 10 human premolars into 15 different parts each and studied the relative amount of innervation present in each area with the transmission electron microscope. Innervation in coronal dentin was found to be more dense than in root dentin. The dentin covering the pulp horns was more densely innervated than other areas of coronal dentin.

The course of these nerves into the dentin is not uniform. Some are described as following a straight course while others spiral around the odontoblastic processes.(50) Avery and Cox(51) believe that the spiraling does not exist, but that what was observed is really the dilation and constriction of nerves on one side of the tubule wall only. However, that a close relationship exists between the nerve fiber and the odontoblastic process is agreed upon.(48,50,51) Several researchers have identified some "accessory cells" or "terminal swellings" in the dentinal tubules.(49,52,53)

The function of these nerve endings in dentin are not known with precision. Probable functions are pain and control of dentinogenesis.(51) Others have suggested that the nerve endings in dentin are only the results of entrapment as dentin is laid down and, as such, have no function.(54,55) Byers(44) counters that they do have sensory function since an increase in the density of those

nerves "parallels increases in dental sensitivity."

Scott(52) suggests that the nodular "accessory cells/terminal swellings" are sites of heat sensation and that the terminal axons relate to cold sensation. Matthews(56) dissected out the inferior dental nerve in dogs. The pulpal nerves were isolated and the teeth stimulated thermally. He found that some of the nerves responded only to heat while others responded only to cold.

Brannstrom(57) believes that the nerve endings in the predentin and dentin are probably mechanoreceptors (A-delta fibers).

Theories of Dentinal Sensitivity

The evidence cited in the previous section does not explain the sensitivity of dentin but does provide a useful structural basis for the two remaining theories on the mechanism of dentinal sensitivity--the transducer theory and the hydrodynamic theory.

Transducer Theory

It has been suggested that the odontoblast has a special sensory function which is able to account for the sensitivity of dentin.(55,58)

Kelley, Bergenholtz, and Cox(59) have shown that odontoblastic processes can penetrate the dentinal tubules up to the dentino-enamel junction (DEJ). The intimate association of the odontoblastic process with the nerve endings in the dentin and the presence of nerve endings in the odontoblastic zone(50,51,60) is evidence that the theory is presently structurally acceptable.

However, Fearnhead(47) was not able to discover any evidence of an actual synapse between a specific nerve and an odontoblast. Frank(50) notes that while the nerve fiber contains a "great number of organelles," the odontoblastic process does not.

If odontoblasts are sensory transducers, then their destruction may be expected to decrease dentinal sensitivity. Nayler(61) attempted to test that by using silver nitrate to precipitate the protein in exposed dentin.

In thermal tests, the silver nitrate group reacted no differently in sensitivity than did the control group. However, Naylor admitted that the silver nitrate may not cause the thorough coagulation of the odontoblastic processes and that silver nitrate may be ineffective in impairing the function of the odontoblast and its process.

Hydrodynamic Theory

In 1850, Neill proposed a hydrodynamic theory of tooth sensitivity which was vigorously attacked by others in the dental profession.(62) Gysi(63), in 1900 again proposed the hydrodynamic theory. He reasoned that since the dentinal tubules are filled with fluids and since fluids are practically incompressible, fluid movement at one end of the dentinal tubule would cause an equal movement at the opposite end of the tubule. This fluid movement causes a "pressure" or a "drawing" on the nerves interwoven with the odontoblasts. The mechanical stimulation of these nerves results in the perception of pain.

The presence of mechanoreceptors in the pulp has been demonstrated by Narhi, Hirvonen, and Hakumaki(64) in a series of experiments on dogs. They concluded that mechanosensitive A-delta fibers exist in the dental pulp. Brannstrom(57) concurs and believes that they are to be found in a "plexus at the periphery of the coronal pulp." In addition, Brannstrom suggests that small c-fibers exist in the pulp center which are also mechanoreceptors, but are

not as easily activated at the A-delta fibers. These c-fibers may produce dull pain on stimulation. Others note that the nerves in the predentin and dentin described previously are supportive of the hydrodynamic theory. (48,50,52)

Several in vitro studies on freshly extracted human teeth have shown that fluid movement in dentinal tubules is possible. Berggren and Brannstrom(65) found that a rate of flow in the tubules of 2-4mm per second is possible through capillary forces. Brannstrom, Linden, and Johnson(66) demonstrated that drilling, an air blast, and heat could cause fluid movement in vitro. The effects of thermal changes were observed by Brannstrom and Johnson.(67) Cold was found to produce a more rapid initial flow than heat. A combined in vivo and in vitro by Johnson and Linden(68) demonstrated that the pressure required to produce pain in teeth was on the same order as that required to produce fluid flow in dentinal tubules.

Thus, conditions which cause dehydration of, or pressure on, the dentinal tubule system are viewed as being able to create sufficient fluid flow to excite the mechanoreceptors at the pulpal-dentinal junction (PDJ). Brannstrom(69) says that "probing, chiseling, or drilling of wet dentinal surfaces without frictional heat would seem to remove liquid mechanically out of the tubules." Brannstrom and Johnson(67) were able to demonstrate that four minutes

of normal evaporation of exposed dentin in vivo mobilized sufficient outward fluid flow to aspirate all of the odontoblasts into the tubules. Brannstrom and Astrom(70) demonstrated that absorbent paper placed against exposed dentin caused pain while the same paper soaked in isotonic saline did not.

Certain substances have been found to cause pain when applied to dentin. Sugar, calcium chloride, and acids are examples. Anderson(43), based on the results of earlier research,(71-73) suggests that these substances cause pain because the osmotic pressure they exert. The more powerful the osmotic pressure exerted, the more pain producing the substances are expected to be. Brannstrom and Johnson(74) disagree, saying that no osmosis is involved because of the lack of a semi-permeable membrane. They assert that these solutions exert a dehydrating effect on dentin by their ability to mobilize capillary forces.

The most serious challenge to the hydrodynamic theory comes from the recent study by Pashley et al.(75) who found progressive decreases in dentin permeability following cavity preparation in dogs. If decreased permeability is related to a decreased ability of the substances in the dentinal tubules to transfer mechanical energy, then postoperative sensitivity would be difficult to explain with the hydrodynamic mechanism.

Thermal Effects on Teeth

Pain

The precise mechanism of dentinal sensitivity is not known (see previous section). Thermal changes were once thought to stimulate the nerves of the pulp directly by thermal conduction through the teeth(61). Brannstrom and Johnson(67) write that "the idea of thermal 'shock' to the pulp undoubtedly had its origin in the experience of pain, especially that elicited by cold, just after an amalgam filling has been placed." The implication was that the amalgam allowed the thermal change at the pulp to proceed more rapidly than normal because of its thermal conductivity.

Several studies have provided evidence for a mechanism of thermal sensitivity which is not caused by simple thermal conduction from the tooth's external surface to the sensory nerves of the pulp. These studies have shown that the sensory response is felt much faster than a measurable temperature change occurs at the pulpal-dentinal junction (PDJ).

Hensel and Mann(76) thermally tested human maxillary incisors and found that pain first appears when enamel is heated to 47.7 C and cooled to 26.4 C, during which the temperature of the pulp underwent no significant change. Naylor(61) measured the time necessary to effect a 0.003 C temperature change in the pulp from a 10 C cold water

stimulus applied to dentin in vitro. Comparisons were made against in vivo sensory reaction times to teeth similarly prepared. In most cases, the time necessary for a temperature change of 0.003 C was greater than the sensory reaction time. Trowbridge, Franks, and Korostoff(77) conducted thermal tests on human premolars in vivo. Sensory response times to hot and cold stimuli were noted. The teeth were then extracted and tested in vitro to measure the time necessary for a temperature change to be noted at the (PDJ). In all cases, the sensory response times in vivo were less than the times necessary for temperature changes to be measured at the pulp.

Thermal Changes and Pulpal Effects

Beveridge and Brown(78) explored the effects of heat and cold on the pulpal blood pressure in human teeth. The effects were not the same. Heat applied to the teeth resulted in large increases in intrapulpal pressure. Pulse pressure also increased and remained high even after the intrapulpal pressure had returned to normal. The higher intrapulpal pressure tended to remain for extended periods after the stimulus was removed. Cooling the teeth caused large decreases in intrapulpal pressure. Pulse pressure was observed to sometimes nearly disappear at the lowest intrapulpal pressure. Unlike the response to heat, the decreased intrapulpal pressure resulting from cold usually returned to its pre-test level rapidly. Beveridge and Brown

noted that the changes in intrapulpal pressure reached their greatest values many seconds after the initiation of the stimulus. Thus, they suggest that the effects observed in their experiments were direct reactions to temperature changes at the pulp vascular system. They do not believe that the responses were mediated by any sensory responses.

Pohto and Scheinin(79) used direct microscopy to view the effects of pulpal temperature changes on the pulpal circulation in lower rat incisors. Blood flow was noted to increase with pulpal temperature increases and to decrease with pulpal temperature decreases. Blood stasis and thrombosis were observed after 30 seconds exposure to 46-50 C pulpal temperature. The freezing of pulpal tissue caused necrosis.

Zach and Cohen(80) were able to induce accurate pulpal temperature rises in monkeys. An increase of 4 F produced only minor tissue changes. An increase of 10 F caused aspiration and destruction of the majority of odontoblasts. However, healing was observed in one week and most teeth showed healthy pulp tissue at 56 days. Necrosis was common in teeth exposed to a 20 F temperature increase and always observed in teeth exposed to a 30 F change. The teeth were heated for 5 to 20 seconds to obtain the desired temperature rises in the pulp.

Conflicting results were obtained when Lisanti and Zander(81) studied the effects of heat in the teeth of dogs.

They applied heat to the pulpal floors of experimental cavity preparations. Temperatures of 125, 150, 200, 300, and 600 F were applied. Temperature increases at the pulp ranged from 3.0 to 44.6 F for the five second exposure and from 13.8 to 91.5 F for the one minute exposures. Results showed that in all cases where thermal damage was observed, the pulp had apparently healed in two months. No pulp deaths were observed even though a 10 second application of 600 F caused extensive destruction and blister formation in the pulp which extended below the coronal portion of the pulp. A similar experiment by Postle(82) yielded similar results.

The above studies agree that the pulp is capable of healing the damage produced by single, short duration exposures to fairly high temperatures, i.e. 200 F. Such temperatures probably occur infrequently in the mouth. Brannstrom(58) suggests that if thermal damage occurs in the pulp it is probably a result of improper dental procedures and that the normal temperature changes of short duration which occur in the mouth are not a problem. However, Peters and Augsburger(29) expressed concern that chronic temperature changes in the pulp may lead to atrophic changes or to a predilection to bacterial invasion through anachoresis.

Factors Which Increase Clinical Sensitivity

Postoperative sensitivity after the placement of an amalgam restoration has been attributed to hyperalgesia resulting from pulpal inflammation and to factors which potentiate the hydrodynamic mechanism.(57,83,84)

Inflammation and Hypersensitivity

Stephan(86) correlated thermal changes with the histologic condition in the pulp. Heated gutta percha and ice were used as stimuli. Patient response time, the severity of the pain, and the duration of the pain were noted. The teeth were then extracted and serial sections prepared for histologic study. Results showed that acute inflammation in the pulp is correlated with more severe pain responses to thermal stimuli which last longer than normal.

Stephen's results have been repeated in other studies which have essentially the same methodology. (86-88) In the studies of Mitchell and Tarplee(86) and Dachi(87) hypersensitivity was associated with pulpal hyperemia in the absence of other inflammatory signs.

Another study evaluating the correlation between diagnostic data and pulpal histologic findings was one by Seltzer, Bender, and Ziontz(89). They found no correlation between abnormal responses to thermal stimuli and any histologic findings. However, a correlation was found between a normal response to thermal tests and the presence of an uninfamed pulp.

Further support of correlations between pulpal inflammation and hypersensitivity come from the studies using prednisolone preparations on freshly cut out dentin. Prednisolone, an anti-inflammatory agent, was successful in reducing postoperative thermal sensitivity under both amalgam and silicate restorations. (90-93)

Causes of Pulpal Inflammation: Operative Procedures

It is commonly believed that operative procedures are capable of producing inflammatory reactions in the pulp. Cutting the odontoblastic processes,(94) aspiration of the odontoblasts,(57) heat production,(94-96) desiccation of the dentin,(74,97,98) malleting,(99) and pressure(100,101) on the teeth are suspected mechanisms. In general, the effects of rotary cavity preparations--cutting of dentinal tubules and odontoblastic processes, aspiration of odontoblasts, heat production and desiccation of the dentin--are not completely understood.

Brannstrom(57) believes that the aspiration of odontoblasts is of no consequence to the pulp providing the cells in the cell rich zone are intact.

The idea that heat production from rotary instrumentation can be hazardous to the pulp has been an area of controversy. Investigators have shown that temperatures generated by high speed instrumentation can be very high--in excess of 1000 F.(102) However, even though the generated temperature increase may be very high, the

total caloric heat production may be very low and thus be of little consequence.(102) The important clinical question has always been "what is safe?"

To insure pulpal health, air and water coolants have been used. A study by Carlton and Dorman(103) found a significant temperature rise in both the dentin and pulp during dry cavity preparation but a decreased temperature during wet preparation. Bhaskar and Lilly(104) found a significant temperature drop in the pulp of 2.5 C using high speed with air coolant and a drop of 8.1 C using the high speed with water coolant. They questioned whether or not the cooling effects were safe.

Some argue that the effects of the heat are minimal and that pulpal effects are probably caused by desiccation of the pulp.(104-106) However, numerous studies do indicate that pulpal trauma is greater during dry preparation than during wet.(98,102,105,106) However, Marrant(102) believes that it is difficult to determine if the trauma is caused solely by the desiccation, heat, or some combination of both. His study on high speed cutting found that with wet cutting there was a 60 percent chance of having no pulpal reaction while there was a 20 percent chance of no reaction with dry cutting.

Kakehashi, Stanley, and Fitzgerald(107) prepared experimental cavities in the teeth of germ free rats and found that some minimal pulpal inflammation was present in

every specimen--results which can be attributed only to the effects of cavity preparation.

Kalins, Millsop, and Natkevicious(99) investigated the effect of malleting gold foil into teeth. Postoperatively, the teeth were said to be slightly sensitive to cold water and other thermal irritants (unspecified). The teeth were extracted for histologic examination a few days after the placement of the restoration. Hemorrhage was found in all adult teeth in the coronal and root pulp. Some teeth showed perivascular infiltration of inflammatory cells.

Pressure on the teeth can occur during operative procedures such as wedging, condensing, cementation of cast restorations, and improper use of elevators during surgery. Postoperative pressure can result from high restorations. Orthodontic procedures are well known as a source of pressure on teeth.

Guevara and McClugage(101) demonstrated that intrusive pressure on teeth can compromise the pulpal blood supply. Edwall(108) found that the excitability of the sensory neuron in the teeth of cats temporarily increased when the blood supply was diminished. Stenvik and Mjor(109) orthodontically intruded human premolars on children whose teeth were to be extracted for orthodontic reasons. Extractions were performed at periods from 4 to 35 days. Histological examination led them to conclude that "inflammation was not a characteristic reaction. . . . and

most changes may be classified as degenerative in nature." A series of studies by Landy and Seltzer(100) used high restorations in rats to study the effects of the intrusive forces of traumatic occlusion. The pulps of the teeth examined at intervals up to three months were histologically normal. However, the 7 to 10 month and later specimens began showing significant concentrations of macrophages and lymphocytes in the pulp.

Brannstrom(57) says that operative procedures may cause some degree of "necrosis in adjacent pulp tissue, but if infection is not involved, there will be no appreciable inflammatory reaction." The implication is that postoperative sensitivity will also be not appreciable. However, Dachi(87) and Mitchell and Tarplee(86) have shown that very mild inflammation is still associated with hypersensitivity.

Causes of Pulpal Inflammation: Thermal damage

de April(110) studied the effects of a stream of water heated to 113 F on the formative dental tissue of rats. Hyperemia of the pulpal blood vessels was found. As the water temperature was raised, more severe inflammatory changes were noted.

Pohto and Scheinen(79) used direct microscopy to observe pulpal changes with temperature. Temperature elevations caused increased permeability of the blood vessels. Stasis and thrombosis were noted at 46 to 50 C.

Postle(82) applied high temperatures to intact dog teeth. Temperatures of 285, 395, and 900 F were used. Specimens examined at one week showed inflammation present in all cases. Marked inflammation was observed in the 900 F series where severe burn lesions in the pulp were noted.

Del Balso, Nishimura, and Setterstrom(111) measured the amount of pulpal histamine found after cavity preparation designed to produce thermal injury. The preparations were cut at 100,000 rpm with no coolant. A fourfold increase in pulpal histamine levels were found in the experimental teeth when compared with the control teeth.

Causes of Pulpal Inflammation: Bacteria

Studies indicate that bacteria may be the major contributory factor towards inflammation in the pulp. Whenever caries is present with open dentinal tubules between the carious lesion and the pulp, an inflammatory reaction can be found in the pulp adjacent to those dentinal tubules.(111) Brannstrom(57) was able to demonstrate an inflammatory reaction in the pulp underneath "white spot" lesions.

Bergenholtz and Reit(112) sealed cultivated plaque bacteria against the cut dentin of monkey teeth. Other teeth received the same treatment except that the dentinal tubules were sealed off by rubbing calcium hydroxide into them prior to the placement of the bacteria. The majority of the teeth with the untreated dentin showed severe

inflammation or total pulpal necrosis while the majority of the control teeth showed only slight inflammation.

Bergenholtz(113) showed that bacterial products were also able to produce pulpal inflammation. Lyophilized bacterial components were sealed into test cavities of monkeys. The teeth were harvested 32 hours later. Histological examination showed that the bacterial products elicited marked inflammation in the pulp area adjacent to the cut dentinal tubules. Abscess formation was frequently found. Control teeth which had similar test cavities showed disruption of the odontoblastic layer but little or no inflammation.

Experiments with germ-free and conventional animals gives further support to the important role of bacteria in the production of pulpal inflammation. Kakehashi, Stanley, and Fitzgerald(107) exposed pulps in germ-free and conventional control animals. The animals were killed at various intervals, from 1 to 42 days postoperatively. After the eighth day the control animals showed, without exception, complete pulpal necrosis with chronic inflammation and abscess formation. Colonies of microorganisms were seen throughout the pulp. No evidence of repair formation occurred. In the germ free animals, minimal inflammation was found in all specimens. Dentinal bridging was seen in 14 days. Necrotic tissue was walled-off and no devital pulps were found. Watts(114)

applied silicate and zinc phosphate cements to exposed pulps in conventional and germ free animals. Both cements produced extensive necrosis in the conventional animals with a great many of the teeth showing apical abscesses. In the germ free group, however, only limited necrosis was found and all of the teeth had dentinal bridges.

Investigations have revealed that bacteria can grow in the contraction gap underneath restorations.(57,115) Sources of these bacteria include (1) the smear layer, (2) bacterial contamination of the preparation before restoring, (3) microorganisms left in the dentinal tubules, and (4) the oral cavity through leakage around the restoration.(57)

Microleakage is posited by some to be a major cause of postoperative sensitivity. Restorations of amalgam, composite, and silicate cements have been demonstrated to have contraction gaps which permit microleakage.(117-119) While Seltzer and Bender(112) report that they could not experimentally produce bacterial penetration at amalgam margins, Mortenson et al.(120) were able to do so. They subjected their experimental teeth to temperature changes. The different coefficients of expansion of tooth structure and amalgam allowed the test bacteria to penetrate the amalgam-tooth interface of their samples.

Brannstrom, Vojinovic, and Nordenhall(116) demonstrated that the bacteria growing underneath restorations can cause

pulpal inflammation. Deep (2.5mm) cavities were prepared on the buccal surfaces of intact premolars which were to be extracted for orthodontic purposes. Silicate cement, known for its poor sealing properties, was placed directly on the exposed dentin with no intervening bases or liner. The silicate cement was itself sealed with a cap of zinc oxide and eugenol to prevent ingress of bacteria from the oral cavity. No attempt was made to introduce bacteria into the preparation. The teeth were extracted in four weeks, fixed, and examined histologically. Bacterial growth was found on 11 of 70 cavities. Slight to moderate inflammation was seen in the pulps of those 11 teeth. The other 59 teeth were free of such reactions.

Causes of Pulpal Inflammation: Chemical Irritants

Many of the substances used in dentistry can be associated with some degree of pulpal inflammation. The following is a list of substances which are or have been used in cavity preparations.

<u>SUBSTANCE</u>	<u>PULPAL REACTION</u>
1. acid etching	inflammation (may be due to increased dentin permeability to noxious products (57,112))
2. acrylic resins	severe inflammation (112,121)
3. amalgam	safe(121), mild irritation (112)
4. calcium hydroxide	moderate inflammation (121)

5. camphorated para-chlorophenol	inflammation (121)
6. chlorohexidine	no reaction (121)
7. composite resins	moderate inflammation (34,112,121)
8. copper cement	severe inflammation (121)
9. cyanoacrylate cements	mild mild to moderate inflammation (112)
10. fat solvents (ether, chloroform, xylol, acetone)	severe inflammation (121)
11. gold	no reaction (112)
12. gutta percha	moderate inflammation (112)
13. hydrogen peroxide	inflammation (112,121)
14. penicillin	inflammation (121)
15. phenol	severe inflammation (112,121)
16. polycarboxylate cement	mild inflammation (34,112,121)
17. silicate cement	severe inflammation (34,112,121)
18. sodium fluoride	no reaction (112,121)
19. stannous fluoride	no reaction (112,121)
20. steroids	no direct pulpal damage but allows pulp pathology to continue (112,121)
21. varnish	no reaction (121)
22. zinc oxide/eugenol	mild inflammation (34,121), irritating if applied directly to the pulp (112)
23. zinc phosphate cement	severe inflammation (112)

Brannstrom (57) stresses that many of the studies which

condemn silicates and composites as being highly dangerous to the pulp are actually reflecting a different shortcoming of the materials. Both silicates and composites are known to have contraction gaps which allow bacterial growth underneath them. Brannstrom believes that the severe pulpal reactions noted with these materials are more likely caused by the bacteria than to the materials. He writes, "A cytotoxic effect can occur initially if these materials are placed very near or directly on the human pulp but the cellular necrosis does not appear to be more extensive than that which occurs after capping with Ca(OH)_2 and no inflammation is seen." Avery(121) found that mild inflammation was seen with calcium hydroxide preparations.

Factors Which Potentiate Hydrodynamic Effects

Two factors have been suggested to cause postoperative sensitivity in teeth which are related specifically to the hydrodynamic model of dentinal sensitivity.

First, fluid could fill the contraction gap underneath a restoration and form a fluid reservoir. This reservoir would be in contact with exposed dentinal tubules. Brannstrom(84,86) and Trowbridge(83) have suggested that this additional fluid could potentiate the effects of the normal hydrodynamic system when thermal changes are involved.

Second, Johnson and Brannstrom(122,123) have demonstrated that if the orifices of the dentinal tubules have been opened or widened, as occurs with acid-etching, that dentin surface will be more sensitive. They imply that it is easier to move fluid through larger tubules and thus sensitivity is increased.

Intracoronaral Treatments for Prevention of Postoperative Thermal Sensitivity

Postoperative thermal sensitivity has been a long standing problem in dentistry. One study(124) revealed that 75 percent of patients had experienced post-operative thermal sensitivity following the placement of amalgam restorations.

Various protein coagulents have been used to prevent

postoperative thermal sensitivity. Phenol, silver-nitrate, strontium chloride, and zinc chloride are widely known as dentin desensitizers.(112,125-128) However, some authors(112,126) have stressed that the benefit obtained from their possible palliative actions must be weighed against their possible harmful actions on the pulp. Anderson and Matthews(129) found that silver nitrate and strontium chloride are ineffective in desensitizing dentin when "osmotic" stimulation is applied. Amler and Bevelander(130) and Martin(131) have shown that the protein coagulant drugs can increase the permeability of dentin and thus allow the possibility that potentially dangerous irritants will have freer access to the pulp.

Although fluorides have been applied intracoronaally in many studies,(131-134) none have tested its use for postoperative thermal sensitivity under restorations. The main thrust of fluoride treatment has been towards cervical or root hypersensitivity. Several investigators have claimed good results in reducing cervical sensitivity to thermal irritants with fluorides.(135-138) However, Schaeffer, Bixler, and Yu(139) claim that their fluoride treatment produced no significant desensitizing effect. They claimed that a placebo effect was responsible for any perceived desensitization.

Iontophoresis has been used to potentiate the effects of the various fluoride preparations. Murthy, Talim, and

Singh(135) claim that iontophoresis with one percent sodium fluoride is the method of choice for the treatment of hypersensitive dentin. Good results have been reported in other studies.(132,139) However, Bolt(140) reports that iontophoresis with 2 percent sodium fluoride is not significantly better than 2 percent sodium fluoride alone for root hypersensitivity. Lefkowitz(134) reported that the fluoride used in iontophoresis is not the agent of desensitization. Rather, he thinks that the electric current is responsible because it causes the formation of secondary dentin which, in turn, reduces sensitivity. Seltzer and Bender(112) agree, but state that the "deliberate induction of reparative dentin is not biologically acceptable."

Corticosteroids have been shown to be very effective in reducing postoperative thermal sensitivity.(90-93) However, the Council of Accepted Dental Therapeutics(141) considers the use of these steroids to be experimental. Controversy surrounds the mechanism of action of the steroids. Studies by Dachi and Stigers(142) and Stanley, Swerdlow, and Driscoll(143) suggest that the mechanism of the steroids in desensitization is that they reduce pulpal inflammation. Reduced pulpal inflammation may mean reduced postoperative sensitivity. Langeland et al.(144) contest the belief that the corticosteroids reduce inflammation and contend that these drugs disguise and "conserve a chronic inflammation."

They contend that the use of steroids is probably harmful to the future vitality of the pulp and that the relief of pain which is achieved is temporary. Klotz, Bernstein, and Bahn(145) demonstrated that the use of prednisolone directly on the pulp could result in bacteremias which they perceived to be potentially hazardous. Mjor and Furseth(146) found that corticosteroids caused obliteration of many of the dentinal tubules, providing an alternative explanation of its desensitizing effects. Blockage of the tubules would interfere with any hydrodynamic mechanism of dential sensitivity. Leonard and Cotton(147) found that the corticosteroids do not penetrate rat dentin in vivo. They suggested that any beneficial effect of the drugs would be mediated through the dentin by the odontoblasts.

Dachi and Stigers(142) found that three layers of copal varnish applied to cavity preparations reduced postoperative thermal sensitivity. Voth, Phillips, and Swartz(28) have shown in laboratory studies that two thick layers of copal varnish have practically no ability to thermally insulate the tooth. Therefore, thermal protection could not be the mechanism by which the varnish reduced thermal sensitivity. Many investigators(39,118,119,148) have shown that copal varnish will reduce microleakage around amalgam, thereby preventing the entrance of irritating factors to the dentin. Dachi and Stigers suggest also that the effect could, in part, be due to the sealing of the dentinal tubules.

However, Frank(121) cautions that liners and varnishes may not be impervious sheaths.

The most traditional treatment for postoperative thermal sensitivity has been to place insulating bases underneath amalgam restorations. Tibbetts (149) and Harper (150) measured in vivo thermal diffusion through bases and restorative materials. No sensitivity measurements were made. In addition, several laboratory studies have been conducted to find the proper base which has insulating properties similar to or better than that of dentin.(27,28,151) However, as described in the prior section "THERMAL EFFECTS ON TEETH," the literature provides ample evidence that the mechanism of thermal sensitivity is not by simple thermal conduction from the tooth's exterior to its interior. To date, only one clinical trial has been conducted to determine the validity of placing thick insulating bases under amalgam restorations for the prevention of postoperative thermal sensitivity. Piperno, et al. (25) conducted a study in which half of their patients had amalgam restorations placed without a base and half with a base. All patients received calcium hydroxide liners and 2 layers of cavity varnish. Surveys by questionnaire, clinical examination, and telephone interview revealed that no differences in thermal sensitivity between the base and no base groups was discernable during any of the three survey periods--24 hours, a week, and six months.

They concluded that cement bases were not necessary under amalgam restorations for thermal protection of the pulp.

Thermal Sensitivity Evaluation in Humans

Various methods have been used to produce thermal stimuli for clinical trials. To date, the researchers who have used thermal stimuli which can be applied precisely reproducible manner are few.

A common heat stimulus is heated gutta percha. (77,78,85-87,90,91,142,152) It is inexpensive and easy to use, but imprecise in relation to the actual amount of heat generated and in relation to its placement on the tooth. Different application pressures and varying amounts of "plastic" gutta percha on the stick could cause variation in the amount of heated gutta percha placed against the tooth and in the amount of surface area of the tooth which is stimulated. Trowbridge, Franks, and Korostoff(77) found that the actual temperatures of the gutta percha stimuli used varied from 68 to 76 C.

For cold stimuli, the most common methods are ice and chloroethane spray or liquid. These methods have the same problems with precision that the gutta percha does. First, the temperature of ice is not always constant. It can be cooler than 32 F. In addition, water films can form on its surface which can affect the applied temperature. No standardized technique for applying ice exists. Researchers

describe using "anesthetic carpules" filled with ice,(86) a "piece of ice,"(122) and "cones of ice."(87,90,91,142) Trowbridge, Franks and Korostoff(77) found that their cotton pellets saturated to dripping with chloroethane resulted in temperatures between 14 and 20 C at the tooth's surface.

Naylor(118) and Mosteller(93) used syringes to inject water at certain temperatures over the teeth but failed to take measures to isolate the other teeth in the mouth from the water stimulus.

Though not used on humans, Matthews(56) was able to develop a method of producing controlled, reproducible thermal stimuli for dog teeth. Water jackets were placed on the teeth. The water which flowed through the jacket was heated or cooled to the desired temperatures by remotely controlled solenoid taps.

Schaeffer, Bixler, and Yu(139) constructed a water cooled and heated metal probe. Hot and cold running water were mixed and run through piping to heat or cool the metal probe. Temperatures at the probe were reproducible to within 1 C.

The criteria for evaluating the response to thermal stimuli are usually measured in terms of the severity of response, the duration of response, and of the sensory response time (time from stimulus application to perception).

The evaluation of the severity of response is, of

necessity, subjective since the patient must be queried. Some researchers have given no explanation of the criteria used in the evaluation of sensitivity.(85,86,136,152,153,154) Others have used arbitrary rating scales in which the patient is asked to judge the severity of the sensation. Gracely, et al.(156) have studied the various methods of pain measurement. They conclude that verbal descriptors "may provide the best method of scaling different dimensions of the pain experience." In the reports of Dachi(87); Dachi, Ross, and Stigers(90,91); and Dachi and Stigers(142), patients were asked to note their responses as "none, mild, moderate, and severe." Johnson and Brannstrom(122) used cross arch comparisons to rate the comparative sensitivity of different treatments. Different operative techniques were performed on contralateral pairs of teeth which were to be extracted for orthodontic reasons. The patient, unaware of the purpose of the test, was asked if he could detect any difference in sensitivity between the two teeth after they were thermally stimulated.

The measure of duration of pain and the sensory response time are also subjective because the patient is often asked to signal when sensation begins and when it ebbs. Verbal descriptors have been used to attempt to help the patient know when to respond. Trowbridge, Franks, and Korostoff(77) instructed their patients to signal by hand

the moment they perceived sensation. However, most other researchers have given no explanation of the verbal descriptors used or if any criteria for sensation were used at all.(85,86,152)

Several studies used a survey method to gauge the thermal response. Piperno, et al.(25) gave their patients postcards which were to be mailed at 24 hours and one week. Telephone interviews were conducted at six months. The patients were asked to signify if they had either hot or cold sensitivity during the time period indicated. Other studies simply asked their patients by telephone or by personal interview at certain intervals if any differences in sensation were noticed by the patients.(92,135)

Summary of Literature Review

Postoperative thermal sensitivity following the placement of amalgam restorations is a continuing problem in dentistry. Attempts to combat the problem have only been partially successful. The treatments known to effectively eliminate hypersensitivity, excluding endodontics, may not be biologically acceptable to the pulp. The problem is made more difficult since the precise mechanism of dentinal sensitivity is not known. As such, researchers have no clear idea of how to defuse the mechanism.

The traditional means of preventing postoperative thermal sensitivity has been to place insulating bases

underneath the deeper amalgam restorations.

METHODS AND MATERIALS

Seventeen individuals who were patients at The University of Michigan School of Dentistry consented to take part in this study. Fourteen patients completed the required two appointments and constitute the final subject population. This population was composed of four males and ten females. Their ages ranged from 14 to 36 years with a mean age of 20.7 years.

The criteria required for acceptance into the study were: (1) virgin occlusal caries present in a mandibular posterior tooth restoration of which entails a "B" or "C" depth cavity preparation.(21) A "B" depth cavity is defined as one which "extends into dentin beyond the minimal depth required by mechanical and biological factors. There is no serious encroachment near the pulp. A substantial thickness of dentin remains." A "C" depth cavity was defined as one which "extends into dentin to such an extent that only a thin, but intact, wall of dentin remains"; (2) no history of spontaneous pain, no radiographic evidence of carious exposure, and no evidence of periodontal disease surrounding the tooth; (3) patient availability for two appointments, one week apart; and (4) patient in good physical health. Three patients were dismissed from the study. One had a carious exposure of the pulp, one had occlusal caries of

insufficient depth, and the other had a previous occlusal restoration.

The investigator was responsible for all phases of the study including: examining the patient, performing all thermal tests, preparing the cavity preparations, mixing the cements, making the impressions, dies, and inlays, and for placing the final restorations. Efforts were made to insure a consistent procedure from patient to patient.

The experimental procedure consisted of (1) thermal tests prior to anesthesia and tooth preparation to establish the preoperative baseline sensitivity for each tooth, (2) preparing inlay preparations in each tooth, (3) fabricating an "ideally based amalgam inlay" and a "no-base amalgam inlay" in the laboratory, and (4) on a subsequent appointment, measuring the patient's sensory response time to a cold water stimulus applied when each amalgam inlay was in place. As such, each patient was his own control and a comparison was made between the sensory response times of the "with base" inlay and the "no base" inlay. After completion of the experimental portion of the study, a final amalgam restoration was placed to complete each case.

First Appointment Procedures

The nature and purpose of the research was explained to the patient. If the patient was a minor the explanation was given to both the patient and a parent or legal guardian of

the patient. An informed consent form was signed by the patient or parent/guardian. The patient's health history was reviewed and the tooth clinically examined to assure suitability for the study (Figure 1).

Using a commercial stock tray*, a rubber base impression** was taken of the quadrant. This impression was called the "isolation" impression. The "isolation" impression was designed to provide a standardized method for permitting thermal stimulation of the test tooth only. To do this, that portion of the impression and tray covering the occlusal surface of the test tooth was removed so that when the impression was refitted into the mouth, the occlusal surface of the test tooth was exposed and all of the other teeth in the quadrant were covered. A rim of red utility wax was sealed around the opening to create a reservoir for stimulus fluid and to prevent that fluid from overflowing onto other oral structures (Figure 2).

To stimulate the tooth, the exposed portion of the "isolation" impression was flooded with a standardized cold water stimulus at 10 degrees C. The cold water was

* Getz 400 Sani-Tray--stock disposable impression tray. Teledyne Dental, Getz-Opton Division, Elk Grove, IL 60007

** Permlastic--polysulfide rubber. Sybron/kerr, Romulus, MI 48174

introduced through a 10 cc disposable plastic syringe* with a curved tip which gave good access.

The 10 C water for the syringe was produced by mixing ice water with warm water until the desired temperature was reached. Three styrofoam cups were used. One held ice water and another held warm water while the third was used for mixing the 10 C water. A centigrade thermometer** was used to measure the temperature of the water (Figure 3).

When the proper 10 C stimulus temperature was achieved, the 10 cc syringe was loaded and set aside momentarily while the "isolation" impression was placed into the mouth. A narrow orifice suction tip*** connected to the saliva ejector was used to remove saliva and debris from the occlusal surface of the test tooth and to remove excess water during the thermal test. The suction tip and the cold water syringe were placed in position and the thermal test begun. In each case the suction was placed in the distal part of the reservoir while the fluid was introduced at the mesial (Figure 4).

* Monojet 412--disposable syringe with tapered curved tip. Sherwood Medical Industries Inc., Deland FL 32720

** Centigrade thermometer-- -20 to 110 C. Fisher Scientific catalog #14-985b

*** Lorentz oral surgery suction system--14-0074, size 1 tip. Walter Lorenz Surgical Instruments, Inc. Jacksonville, FL 32218

The patient used a hand-held stopwatch* to measure the sensory response time (see Fig. 3). The sensory response time was defined as the time from introduction of the cold water stimulus into the reservoir of the "isolation" impression until the appropriate sensation in the tooth was perceived by the patient. The stopwatch was started when the cold water stimulus began. The instructions "ready--set--go" were used so that the start of the stopwatch and the stimulus flow could be coincident. A trial run of this procedure was carried out for each patient to insure that the instructions were understood and that the patient was capable of implementing them. The patient was instructed to stop the clock at the first sign of "discomfort" in the test tooth. Patients were instructed to concentrate on the test tooth and to ignore the coolness felt by the oral mucosa as the cold water syringe entered their mouth. The moment discomfort was perceived by the patient and the stopwatch halted, the cold water flow ceased and the "isolation" impression was removed from the mouth so that the test tooth could be warmed by the normal oral environment

A total of three such test runs were done. To prevent temperature changes from being initiated by the "isolation" impression, the impression was placed in a body temperature

* Stopwatch--0.2 second increments. Northwest Instruments. Staten Island, NY 10314

water bath, 37 C, prior to and between all runs. A period of two minutes was allowed between each run to allow the temperature of the tooth to recover (Figure 5).

After these thermal tests were completed the patient was anesthetized and the test tooth prepared. The caries was excavated and the walls of the conservative preparation tapered in a manner consistent with a conventional inlay preparation. In some cases the inlay preparations were simplified. In these, retentive dovetails and extensions, which would normally be placed in inlay preparations, were not made if that area of tooth structure was sound. In other cases undermined cusps, that would normally be removed, were maintained. This practice minimized the potential problems in the seating of the inlays which might be caused by the more complex design. After the thermal tests were completed in the second appointment, all teeth were reprepared as required to complete conventional cavity preparations.

The instrumentation used in cavity preparation included a high speed handpiece with water spray coolant and a slow speed handpiece with steel round burs for caries removal. Chisels, hatchets, and other hand instruments were used as appropriate.

If a pulpal exposure occurred on a tooth, that tooth received the standard treatment for such cases and was then eliminated from the study.

Following caries excavation, the dentinal tubules of the sound dentin were sealed with two layers of cavity varnish*. If the walls of the preparation were undercut, the undercuts were filled with a zinc phosphate cement**. The application of cement to the pulpal floor was avoided.

An impression of the inlay preparation was made using an addition-reaction silicone*** in a Getz 400 Sani-Tray stock tray. The material was syringed into the preparation and followed by the bulk material in the tray (Figure 6).

The impression was then removed and an interim dressing placed. Zinc oxide and eugenol**** was used. Damp cotton fibers were placed on the deepest portion of the pulpal floor to facilitate the later removal of the temporary at the second appointment. The patient was dismissed.

* Copalite--intermediary varnish and dentinal tubule seal. Cooley and Cooley, Ltd. Houston, TX

** Tenacin--zinc phosphate cement. Powder lot #120581, liquid lot #110681. L.D. Caulk Co. Milford, DL 19963

*** President--polyvinylsiloxane addition silicone. Coltene Inc. CH-9450, Altstaelter, Switzerland

**** Ward's TempPak--temporary cement. Westward Dental Products Co. San Francisco, CA

Laboratory Procedures

The amalgam inlays were fabricated in the following manner. The impression of the preparation was poured with vacuum-mixed die stone*. At least three dies were formed from each impression. One die was for the "no base" amalgam inlay, one was for the "with base" amalgam inlay, and the extra was for checking the fit of the inlays made on the other dies.

The dies were prepared for inlay fabrication by first introducing a cyanoacrylate cement** into the preparation in order to help the dies resist forces of the inlay fabrication, ie. the condensing and carving of the materials. The excess cyanoacrylate was blown out of the preparation with a gentle air blast and allowed to dry (Figure 7).

As an aid in the removal of the inlays from the tooth in the mouth and in order to affix the zinc phosphate base to the amalgam of the "with base" inlay, 5-0 nylon sutures*** were used in the inlays. The materials were packed around the suture material so that a loop was formed

* Vel-Mix Stone--improved stone. Sybron/Kerr. Romulus, MI 48174

** Wonderbond Plus--cyanoacrylate adhesive. Borden, Inc. Columbus, OH 43215

*** 5-0 Ethicon--black monofilament nylon. Ethicon, Inc. Sommerville, NJ 08876

extending from the pulpal floor of the inlay, passing through the sides of the inlay and out through the occlusal surface (Figure 8).

In the case of the "with base" inlay, the suture held the zinc phosphate base to the amalgam portion of the inlay. The suture loop did not interfere with the seating of the "isolation" impression and permitted convenient and comfortable retrieval of the inlays.

The base and amalgam were placed into the dies using conventional techniques. The base used was zinc phosphate cement. The amalgam was a spherical high-copper alloy*. All materials were prepared in accordance with the manufacturer's instructions. In the "with base" inlay the cement was placed to an "ideal" depth before placing the amalgam. The "ideal" depth was defined as that thickness of base which would restore the preparation to an ideal internal outline form, i.e. approximately 0.5mm into the dentin beyond the deepest enamel. This depth was estimated by the investigator since the stone dies could not record the dentinoenamel junction. Once the base was set, the amalgam was condensed over it and carved to fit the contour of the occlusal surface. In the amalgam inlay without base the amalgam was introduced directly against the pulpal floor of the die and carved in the same manner as the "with base"

* Tytin Capsules 600mg--high copper spherical amalgam, lot # 7918002-022680. SS White Dental Products Int. Philadelphia, PA 19102

inlay (Figure 9).

Once the amalgam was set , the dies were sectioned and broken away from the inlay surfaces (Figure 10). At times the inlays were damaged during this removal procedure. The damaged inlays were discarded, new dies poured from the silicone impression, and new inlays fabricated. The separated inlays were then tried into the third die (Figure 11). The small undercuts which may have existed in the dies were reflected as overhangs which interfered with the complete seating of the inlays. The lateral walls of each inlay were adjusted as required to permit the complete seating of each inlay. In no case was the pulpal floor surface of the inlay adjusted.

Second Appointment Procedures

The second appointment was usually carried out one week after the first appointment although for one patient (patient 2) the second appointment was two days following. The procedure of the second appointment was as follows.

Removal of the temporary was made with a small spoon excavator. No anesthesia was used. Care was taken to avoid any mechanical stimulation of the dentin. The cavity was rinsed with 37 C water to avoid thermally stimulating the tooth. Both inlays were tried into the mouth (Figure 12). Any needed adjustments to the lateral walls of the inlays were performed at that time to assure complete seating. The

inlays were then removed and set aside.

A small amount of distilled water at 37 C was injected into the cavity preparation prior to the seating of the first inlay. As the inlay was seated, the excess water flowed out of the preparation into the oral cavity. In this manner it was insured that no insulating layer of air would remain between the inlay and tooth structure. Water was selected because of its neutral effects on the tooth and because its thermal conductivity, $0.00143 \text{ cal/sec/cm}^2/(\text{C/cm})$, compares favorably to that of dentin $0.0015 \text{ cal/sec/cm}^2/\text{C/cm}$.

After the inlay was seated, the excess water on the occlusal surface was absorbed off with cotton pellets and the amalgam margins sealed using a quick setting zinc oxide and eugenol cavity liner* (Figure 13). The sealing was done to eliminate any microleakage factors which might have affected the results. The seal was applied with small ball burnisher at the margins only. Efforts were made to keep the remaining occlusal surface clear (Figure 14). A check for a good inlay seal was made by directing a strong air stream over the tooth. Incompletely sealed inlays resulted in tooth sensitivity. Those that were not sensitive were judged to be sealed. If the tooth was found to be incompletely sealed, the inlay was removed and the inlay

* Cavitec--cavity liner. Sybron/kerr, Romulus, MI 48174

seating process started over. If the inlay was judged as sealed, the thermal tests were performed as described previously in the FIRST APPOINTMENT PROCEDURES section (Figure 15).

Three test sequences were carried out for each inlay. To prevent any cumulative test effects from influencing the data, one-half of the patients had the "no base" inlay first, followed by the "with base" inlay. The other half began with the "with base" inlay followed by the "no base" inlay.

To remove the first test inlay the suture loop was pulled occlusally and the inlay removed. The zinc oxide-eugenol seal usually came off with the inlay. If not, care was taken to insure that all of the cement was removed from the tooth. The preparation was also inspected for debris and the other test inlay was fitted in a similar manner.

After all of the thermal tests were completed the patient was anesthetized. The tooth was prepared to receive a conventional amalgam restoration. Normal undercuts were made in dentin and the tooth was restored in amalgam.

Three trials were usually taken for the preoperative thermal test and for each experimental inlay. After the first two patients were completed, a need was seen to take a fourth trial when indicated. On several occasions a fourth trial was used if one of the other trials were considered

suspect. A trial would have been considered suspect if any of the following occurred: (1) the stopwatch was mishandled, (2) the water stimulus was misdirected, (3) the "isolation" impression was displaced or not properly seated, (4) the water stimulus was started or stopped too soon, and (5) a large discrepancy was observed between the sensory response times in one series of tests.

All trials in which no sensation was reported by the patient were scored for six seconds, an arbitrary number chosen because only about six seconds of water stream could be delivered from the 10cc syringe.

If any trial was unpleasant for the patient, the patient was offered the opportunity to discontinue any remaining trials or a test series or to dismiss himself from the study without prejudice. All patients who experienced such difficulty elected to continue with the testing. Those patients were instructed to attempt to stop the stopwatch before such unpleasantness was again perceived so that the stimulus could be removed before any severe discomfort occurred.

The entire procedure is summarized in the following outline.

I. First Appointment

1. Make "isolation" impression.
2. Perform preoperative thermal tests.
3. Anesthetize patient.

4. Excavate the carious lesion.
5. Prepare inlay preparation.
6. Make impression of preparation.
7. Place temporary restoration.

II. Laboratory Tasks

1. Prepare stone dies.
2. Construct "with base" amalgam inlay and "no base" amalgam inlay.
3. Remove inlays from dies and fit to extra die.

III. Second Appointment

1. The patient is not anesthetized.
2. Remove temporary with care.
3. Place first inlay as described previously.
4. Perform three thermal tests on first inlay.
5. Remove first inlay and replace with second inlay.
6. Perform three thermal tests on second inlay.
7. Anesthetize patient and finish preparation for final restoration.
8. Place final amalgam restoration.



Figure 1. Preoperative view of tooth. Note caries at arrow.

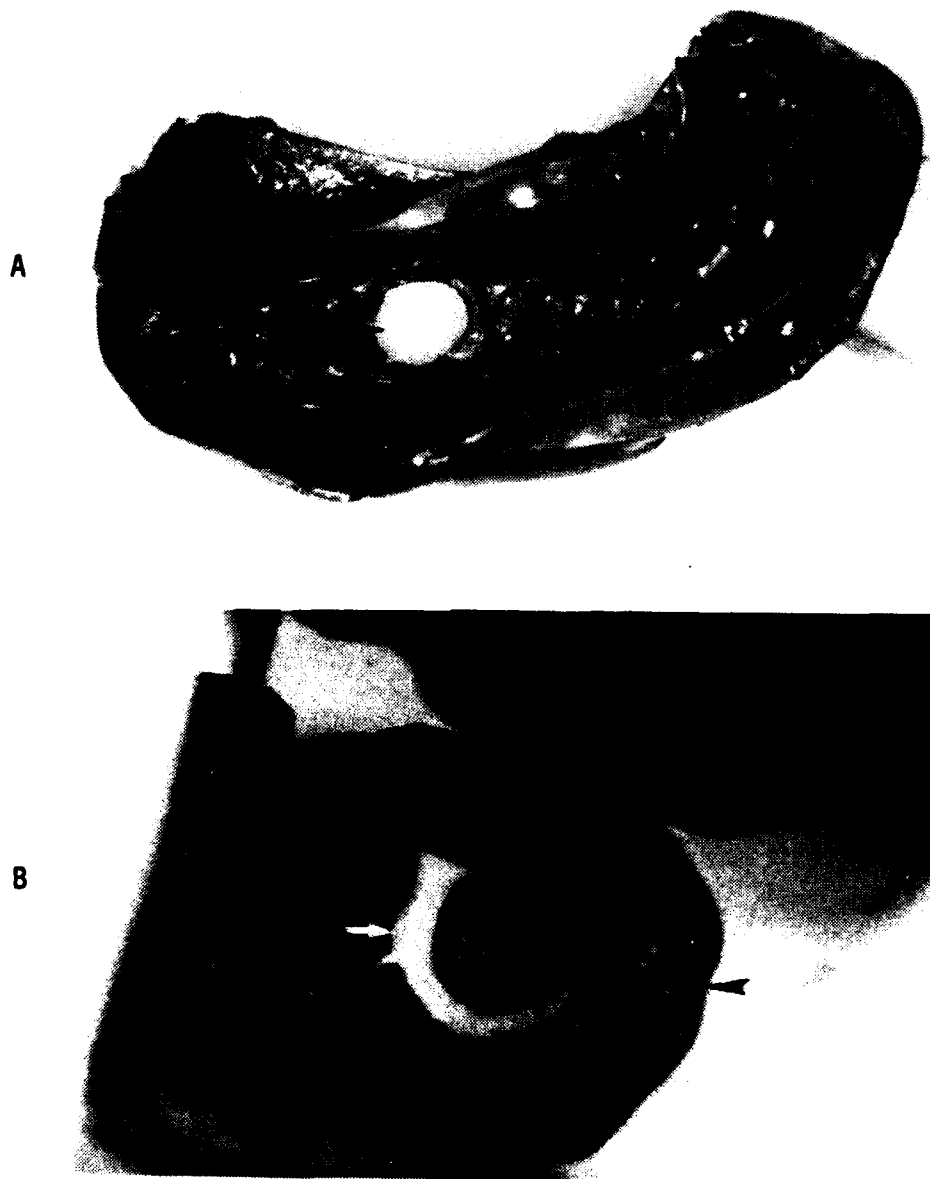


Figure 2. "Isolation" impression. A. Internal view with occlusal portion above test tooth removed. B. "Isolation" impression seated intraorally. Note wax rim forming fluid reservoir.

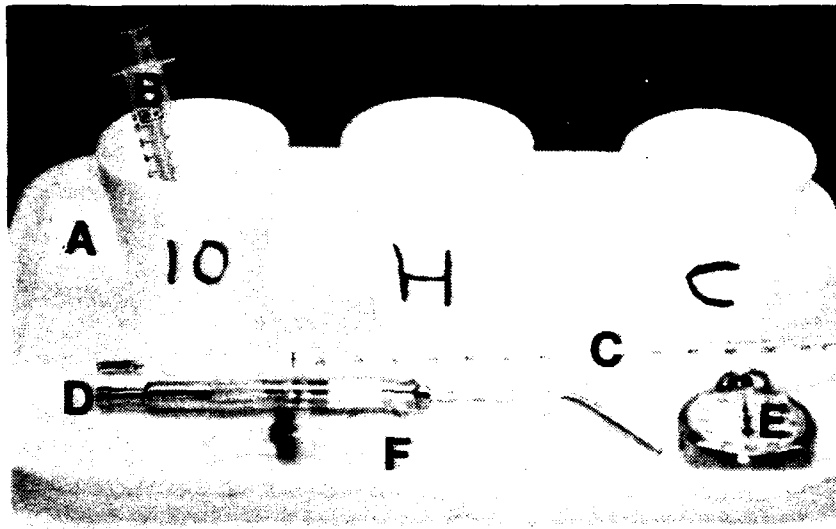


Figure 3. Thermal test tray. A. Styrofoam cups for stimulus preparation: ice water filled the "C" cup, hot water filled the "H" cup, and 10 C water was mixed in the "10" cup. B. Water mixing syringe. C. Centigrade thermometer. D. Evacuation tip. E. Stopwatch. F. Curved syringe to deliver 10 C stimulus.

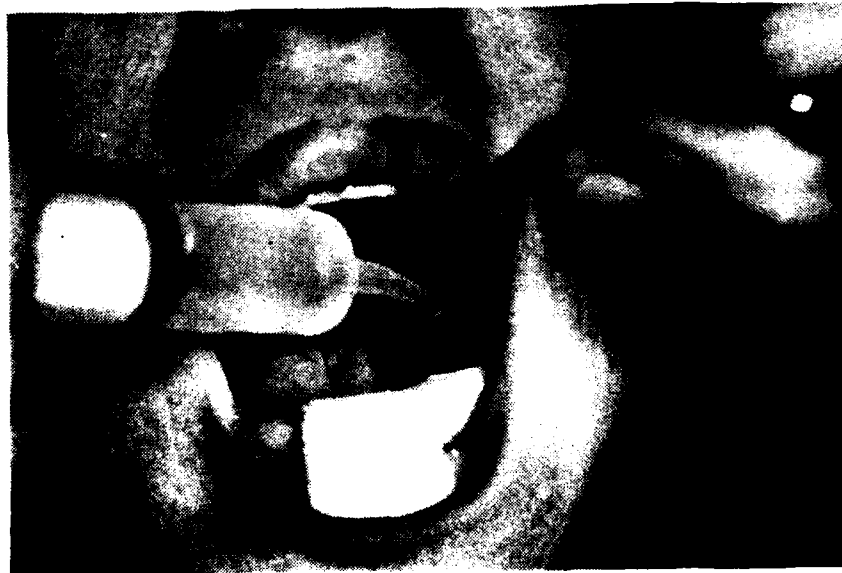


Figure 4. Intraoral 10 C stimulus application.

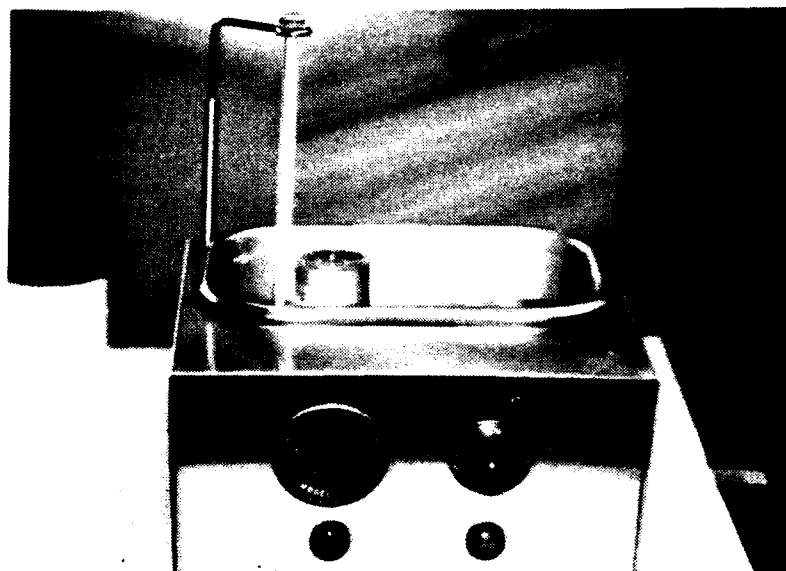


Figure 5. Water bath at 37 C.



Figure 6. Impression of inlay preparation.

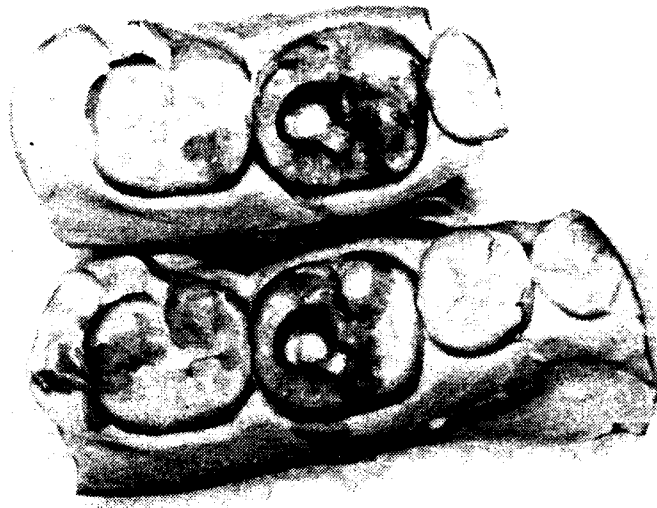


Figure 7. Stone dies with cyanoacrylate cement.

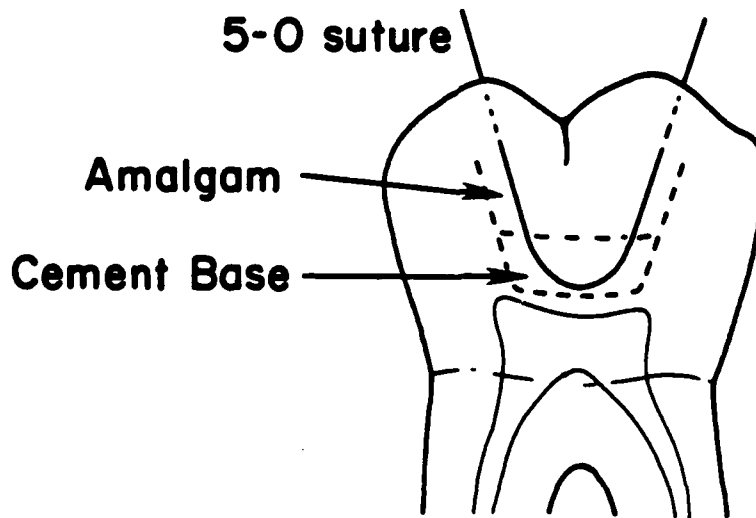


Figure 8. Suture loop through inlay.

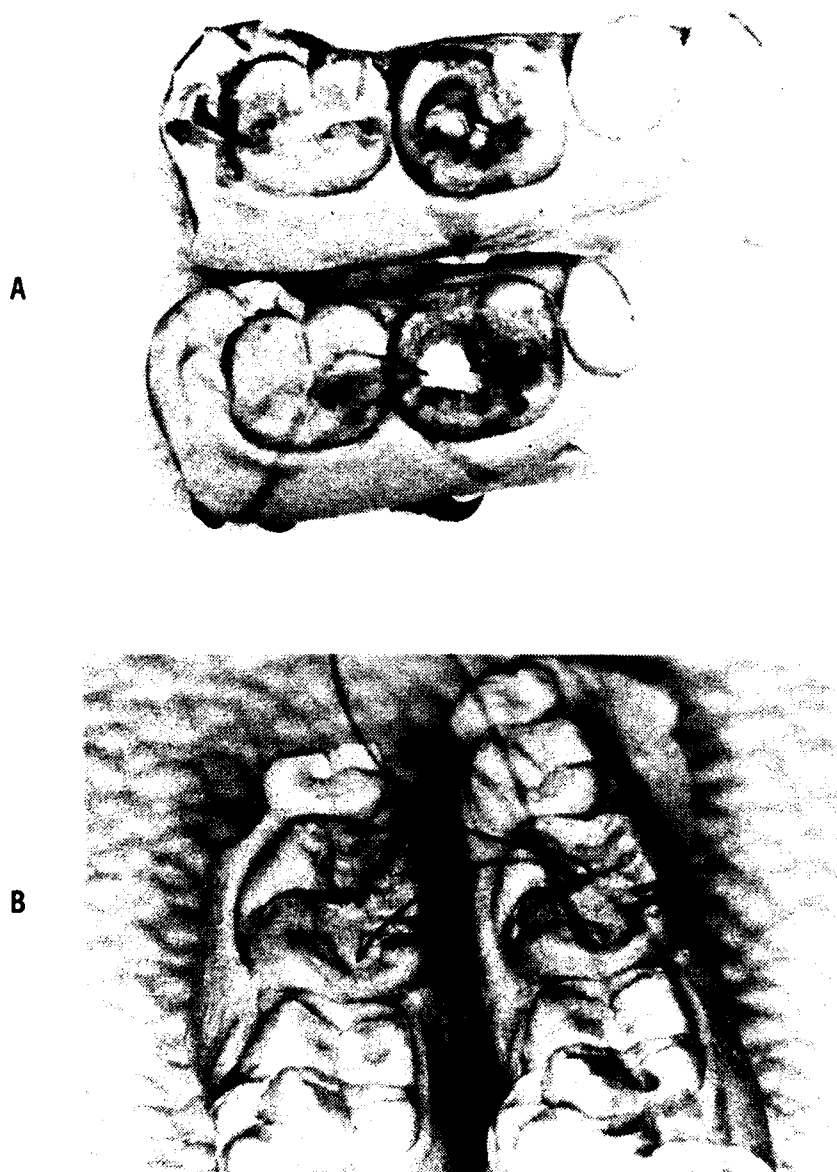
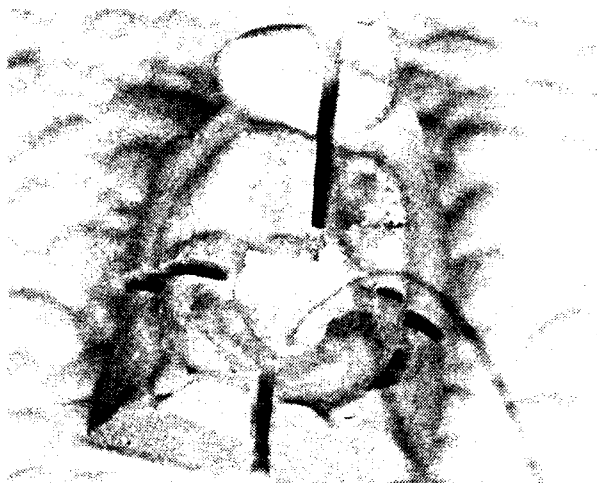


Figure 9. Inlay fabrication. A. Zinc phosphate base with 5-0 suture in place prior to amalgam placement. B. Amalgam carving complete.

A



B

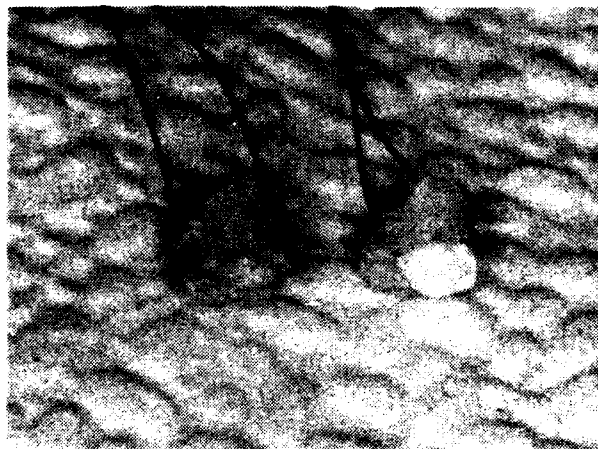


Figure 10. Inlay separation. A. Sectioning die for inlay removal. B. "No base" and "with base" inlays.

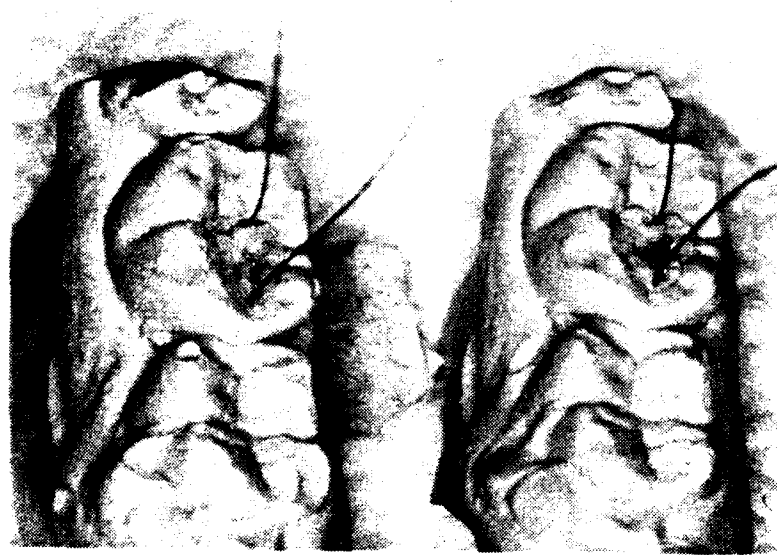


Figure 11. Inlays refitted on dies.



Figure 12. Intraoral inlay placement.

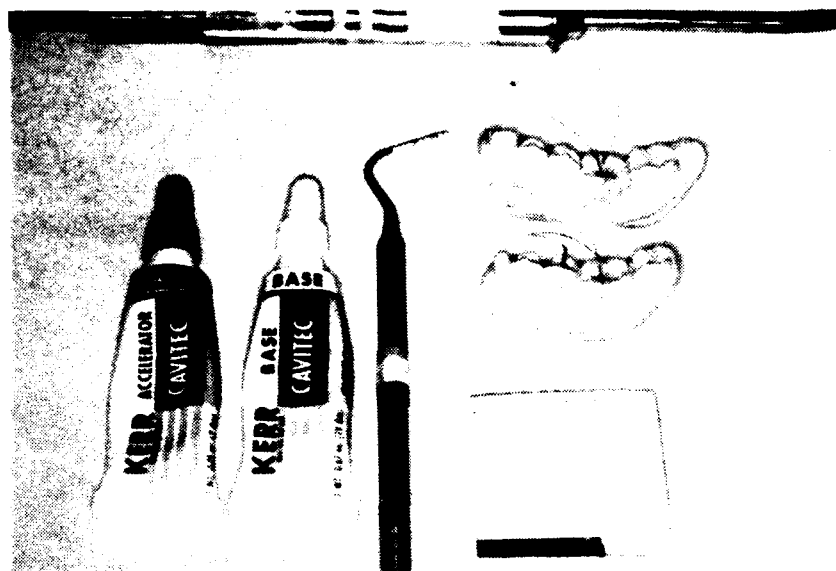


Figure 13. Quick setting zinc-oxide eugenol cement with applicator.



Figure 14. Inlay margins sealed with quick setting zinc-oxide eugenol cement.



Figure 15. "Isolation" impression refitted for postoperative thermal tests.

RESULTS

Seventeen patients consented to participate in the study. Three of the patients were not included in the final data analysis. Of those, one (patient 5) had a prior restoration, one (patient 8) had a carious pulpal exposure, and one (patient 13) did not have caries sufficiently deep to require a cement base. In the 14 remaining patients the following teeth were included for study:

Second molars	8
First molars	5
Second bicuspid	1

	14

The recorded data for all patients are presented in Table 1. Normally, three sensory response times were taken for each category. However, after the first two patients were completed it became evident that some tests were suspect and that an additional test was necessary. The suspect times are listed in Table 1 and these sensory response times were not included in the statistical analysis.

Table 2 lists the means of the trials for each of the 14 patients included in the final data analysis. In 12 of

14 (85.7 percent) patients, the sensory response times were of shorter duration for the "no base" categories than for the "with base" categories. Patients 7 and 12 were the exceptions.

Comparison of the preoperative and "with base" categories showed the same ratio. About 86 percent (85.7) of the "with base" sensory response times were of shorter duration than those of the preoperative category. Patients 3 and 9 had slower sensory response times for the "with base" trials. All of the "no base" sensory response times were shorter in duration than the preoperative sensory response times.

The data from Table 2 was analysed by paired "t" tests to determine if the test categories were statistically different. The results are shown in Table 3. The comparison of the preoperative tests with the "with base" tests showed that even though the preoperative sensory response times were slower than the "with base" times 85.7 percent of the time, the significance of that difference was not high ($p=0.0940$). However, the preoperative and "no base" differences were found to be highly significant ($p=0.0010$).

The comparison between the "with base" and "no base" categories was significant also ($p=0.0071$). In addition, while not a part of the planned data collection, eight of the fourteen patients volunteered the observation that the

"no base" trails resulted in a more severe, uncomfortable and longer lasting sensation than the "with base" trials. The patients were not told which inlay, "with base" or "no base", was in place when they made that admission. After the tests were completed and the results disclosed, many patients expressed the desire that bases be placed in their teeth in the final amalgam restoration.

No significant sex or age differences were shown.

TABLE 1
SENSORY RESPONSE TIMES IN SECONDS AND DEMOGRAPHIC DATA

Patient	Preoperative			Mean	With Base			Mean	No Base			Mean	Sex	Age	Tooth	Caries Surface	
1	3.6	3.1	3.1	3.26	4.6	2.1	2.4	3.03	1.4	1.0	1.4	1.26	F	24	18	M0	
2	3.7	3.4	1.8	2.96	4.0	2.2	2.4	2.86	1.75	3.4	1.8	2.32	M	26	30	M0	
3	4.0	5.4	6.0	5.13	6.0	3.8 ^d	5.2	6.0	2.2	2.4	2.6	2.40	F	14	18	OF	
4	6.0	2.2 ^e	5.6	4.6	5.40	2.0	1.2	1.8	1.67	1.2	0.8	1.2	1.06	F	23	19	0
5*	6.0	6.0	6.0	6.00	6.0	6.0	6.0	6.00	6.0	6.0	5.0	5.67	M	17	19	M0	
6	1.6	2.0	3.6	2.40	1.4	1.2	1.0	1.20	0.8	0.8	0.8	0.8	F	36	18	0	
7	2.0	2.0	1.2	1.70	0.8	0.6	0.9	0.77	1.2	0.8	0.4	0.8	F	16	20	0	
8**	1.9	2.0	1.0	1.63													
9	2.0	1.2	2.8	2.00	1.4 ^b	4.2	3.6	5.4	4.40	1.0	1.2	1.2	1.13	F	15	31	0
10	1.9	1.6	2.0	1.83	1.2 ^c	1.6	1.4	1.9	1.63	1.2	1.0	2.2	1.47	M	17	19	0
11	6.0	6.0	4.2	5.40	3.0	3.4	3.8	3.4	3.4	1.2	3.6 ^c	0.8	1.6	1.20	19	18	0
12	1.6	1.2	0.6	1.13	0.6	1.0	1.2	0.93	1.0	1.0	1.0	1.00	F	16	19	OF	
13***	2.5	2.2	3.6	2.80													
14	1.0	1.4	1.5	1.30	0.8	0.8	1.0	0.86	0.4	0.4	1.0 ^b	0.4	0.40	F	21	31	0
15	1.2	1.0	1.6	1.27	6.0 ^a	0.8	1.2	1.2	1.07	0.7	0.6	0.9	0.73	F	22	18	0
16	1.0	1.2	0.8	1.00	1.4 ^a	0.8	0.8	0.6	0.77	0.4	0.4	0.6	0.47	F	24	19	0
17	5.4	5.4	3.0	4.60	1.4	1.3	1.2	1.30	1.0	1.0	0.8	0.93	M	17	31	0	

Negative responses were scored for 6.0 seconds.

Reason additional test taken:

- a. Stopwatch mishandled.
 - b. Water stimulus mishandled.
 - c. "Isolation" impression not seated.
 - d. Water stimulus started or stopped too soon.
 - e. Large discrepancy compared to other times in series.
- * Patient dismissed from study because of prior restoration in tooth.
- ** Patient dismissed from study because of carious exposure.
- *** Patient dismissed from study because of carious depth - no base required.

TABLE 2
MEAN SENSORY RESPONSE TIMES IN SECONDS BY CATEGORY

Patient	Preoperative	With Base	No Base
1	3.26	3.03	1.26
2	2.96	2.86	2.32
3	5.13	5.25	2.40
4	5.40	1.67	1.06
6	2.40	1.20	0.80
7	1.70	0.77	0.80
9	2.00	4.40	1.13
10	1.83	1.63	1.47
11	5.40	3.4	1.20
12	1.13	0.93	1.00
14	1.30	0.86	0.40
15	1.27	1.07	0.73
16	1.00	0.77	0.47
17	4.60	1.30	0.93

TABLE 3
PAIRED "T" TEST DATA ANALYSIS

Group	Mean	Mean Diff	Std Dev	T-Stat	Significance
Preoperative With Base	2.8129 2.0814	0.73143	1.5146	1.8069	0.0940
Preoperative No Base	2.8129 1.1407	1.67210	1.4759	4.2391	0.0010
With Base No Base	2.0814 1.1407	0.94071	1.1027	3.1919	0.0071

DISCUSSION

Certain practitioners of restorative dentistry have suggested that the routine placement of cement bases under amalgam for thermal protection is an unnecessary procedure. Since this investigator formerly subscribed to that practice, the results of this research were quite sobering.

As described in the literature review, the use of bases was not popular with practitioners in the 1800's. The placement of bases involves an additional procedure and, as such, consumes a certain amount of time. The use of bases as a means of preventing thermal hypersensitivity had not been well substantiated by clinical research.

The results of the only clinical study yet done which studied the question appeared to suggest that bases are not necessary. That study, by Piperno, et al.,(25) while concluding that bases are unnecessary, used a calcium hydroxide cement liner in each tooth. Such a liner qualifies as a base according to some definitions.(21,26) If the semantic problems of bases and liners are put aside, it is obvious that the Piperno study used some thermal insulation under their amalgam restorations in every case. Their conclusion might better have been stated otherwise, that a 0.5mm layer of calcium hydroxide provided adequate thermal protection.

Other evidence has suggested that bases may be

unnecessary as a protection against thermal hypersensitivity. The literature has shown that tooth sensitivity to thermal changes is not dependent upon the transfer of heat or cold to the pulp. Evidence indicates that the sensory responses of a tooth to a thermal stimulus occurs much faster than any temperature change can occur at the pulp. The mechanism for thermal sensitivity has to involve the hard tissues of the tooth. It seemed possible that the patient's response to thermal stimuli could be mediated by the remaining unrestored tooth tissue rather than through the restoration only. As such it was hypothesized that any system of insulation designed to minimize thermal changes in the pulp would be ineffective in preventing thermal hypersensitivity. Under this reasoning, the cases of thermal hypersensitivity seen clinically could be explained in terms of a decreasing threshold to pain due to pulpal inflammation and microleakage around the restoration. The literature supports the view that an increase in pulpal inflammation is associated with increased sensitivity and that most operative procedures are capable of inducing or increasing pulpal inflammation. Techniques such as the application of cavity varnish for reducing microleakage have been shown to reduce thermal sensitivity.

This research was designed to test these views by eliminating any differences in inflammation and microleakage between the "with base" and "no base" samples and by

providing a repeatable, accurate, and realistic manner of thermal testing.

The results at one week show that bases are a highly significant factor in the reduction of postoperative sensitivity. The amalgam "with base" trials were significantly less sensitive ($P = 0.0071$) than the amalgam "no base" trials. The patients were not told which restoration, "with base" or "no base", was being placed into their tooth. However, most had no difficulty in judging which caused the greater sensitivity. Many volunteered that the "no base" trials caused greater pain of a longer duration than the "with base" trials. After the results were explained to the patient, nearly all patients expressed a desire to have a cement base placed before receiving the final amalgam restoration.

One patient, number 5, presented with a mesial occlusal amalgam restoration which had recurrent caries at the margins and underneath the restoration. This tooth was insensitive to the 10 degree C stimulus. Only during one trial, the third "no base" trial, was there any response. Even then, the response was relatively insignificant. Since the tooth was vital, the probable explanation for the lack of sensation could be tied to reparative dentin deposition. It is very likely that the first insult to the tooth several years prior induced reparative dentin formation. That insult included the caries experience and the trauma of the

operative procedures performed to restore the tooth. Reparative dentin can produce occlusion of the dentinal tubules and an additional layer of insulating material.

The results may lead some to hypothesize that cement bases are unnecessary in patients with prior restorations. However, caution should be urged. Reparative dentin formation is not consistent. It varies in permeability, thickness and arrangement. Thermal sensitivity may remain even after several different restorations had been placed. A thermal insulating base would be an appropriate part of the restoration service in these instances. Since the quality and quantity of reparative dentin formation is not predictable in individuals, cement bases should be considered for every patient when the prepared cavity is deeper than is ideal for mechanical reasons.

In addition, the results of this study have shown that in 12 of the 14 patients studied, bases do help reduce thermal sensitivity at one week. Research has shown that significant reparative dentin formation does not occur until after the first month postoperatively. As such, the placement of a base could be helpful to prevent thermal sensitivity during this time period. Not placing a base could subject the patient to discomfort from thermal changes until a sufficient layer of reparative dentin is formed. Certainly, the empirical evidence from this study indicates that bases would be desired by patients if the choice were

offered to them.

Some practioners may sincerely believe that bases for thermal insulation are unnecessary under amalgam restorations because their patients do not frequently complain of thermal sensitivity when the bases are omitted. However, these dentists may be inadvertently preparing their patients to suffer discomfort from thermal change in silence. If a patient is told that thermal discomfort is normal and to be expected for a period of time postoperatively, then that patient is forewarned, and will probably not complain.

Another interesting finding was that the amalgam "with base" trials were slightly more sensitive than the "preoperative" trials. However, the differences were not as highly significant ($P = 0.0940$) as the other findings in the study. This increase in sensitivity may reflect (1) a decreased pain threshold due to the operative procedures, (2) the water under the inlays causing an increased hydrodynamic effect, (3) the difference in thermal conductivity between amalgam and the enamel and carious dentin of the unrestored tooth, or (4) some combination of the preceeding.

Discussion of Methodology

The aim of research such as this should be to provide reliable, accurate data which is free from bias and is reproducible by other researchers. As such, the methodology

should be standardized and regulated to an extent which excludes as much subjectivity as possible. Experiments on sensation have always suffered from subjectivity. This study has attempted to minimize patient subjectivity in several ways.

No efforts were made to have the patients assess differing amounts of discomfort as part of the methodology. Unsolicited comments on such differences, however, were noted and their significance described in the previous section. Rather, patients were only asked to attend to the first perception of sensation in the tooth being tested. It was found that this point of first perception of sensation was easy for all patients to understand and a sensation to which they could respond. All comparisons between the based and unbased conditions were made on the same teeth for each patient. The removable amalgam inlays made this possible. The interchangeable inlays thus eliminated the problems of comparing different teeth on the same patient or between patients and of comparing the same tooth on different days.

Factors which are known to affect the sensitivity of teeth were equalized for both test inlays. The factor of tooth "inflammation" was negated since the inlays were tested only minutes apart on the same tooth. Stimulation during the tests was minimal and those operative procedures which are known to increase pulpal inflammation i.e. rotary instrumentation, pressure, vibration, chemical insults and

desiccation were avoided. The fact that the amalgam inlays were of the same size and were sealed in the same manner minimized any possibility of microleakage differences being a significant factor in prejudging the results.

The method of performing the thermal tests is also unique. The use of the standardized cold water stimulus and the "isolation" impression were important. In the past some researchers have been delinquent in providing means for thermal testing which was both constant in temperature and location of the stimulus areas. As noted in the literature review, heated gutta percha for a heat stimulus and ice for cold have been among the most frequently used thermal stimuli. These methods are very imprecise in their temperature control. The standardized water stimulus used in the study was by contrast accurate and easy to control. The "isolation" impression insured that the same area was stimulated each time. It also proved to be very easy to remove and replace and caused the patient no discomfort. Some researchers have developed sophisticated instruments to insure reliable thermal stimulation, some of which are rather expensive. The method used in this project has as an advantage its low cost and simplicity. It provides consistent temperature flow and has the advantage of insuring that the same exact area of the tooth is being stimulated from trial to trial.

In addition, the thermal testing procedure avoided the

pitfall of testing the effect of thermal changes through only the restoration. In reality, more than just the surface of the restoration is affected when normal thermal changes occur to a tooth. Unrestored tooth structure is affected also. When hot coffee or ice cream are ingested, many as yet unquantified tooth surfaces are affected. Certainly, the whole occlusal surface is stimulated. This experiment used the "isolation" impression to allow the whole occlusal surface of the test tooth only to be stimulated in a consistent manner. As such, since all test restorations involved the occlusal surface, both the restoration and the remaining occlusal tooth structure were affected when the stimulus was applied.

Of course, flowing water over teeth is only useful if the water can be contained. This appears to be practical when used on mandibular teeth. The problem of using this thermal testing procedure on maxillary teeth is obvious. Because of gravity the water flowed onto a maxillary tooth would drop elsewhere. However, if one could insure that he spent water could be immediately scavanged it may be possible to use this technique on maxillary teeth.

Suggestions for Methodology Improvement

Early in testing it became evident that the rate of water flow through the syringe was important. A fast flow directed at the tooth would produce a faster response than a slower flow. Presumably, this was caused by the faster

cooling of the tooth with the higher flow rate. The water contacting the tooth would be expected to be warmed by the tooth and thus increase in temperature. A higher flow rate would remove this warmed water more quickly and replace it with cooler water from the syringe, thus in effect causing a faster cooling of the tooth.

An attempt was made, therefore, to use the same rate of water flow from trial to trial. However, since the syringe was hand-held and controlled by thumb pressure, it cannot be said that the flow rate was truly constant between trials. The variability reflected in the sensory response times between trials (1) and (3) for each test series may be largely a result of the lack of a constant water flow rate. In future research using this type of thermal testing methodology, one should provide a means of insuring constant water flow between all trials. Such instrumentation should be relatively easy and inexpensive to develop and may decrease the amount of variability between trials.

Other factors which were suspected to affect the sensory response times are water syringe tip placement and suction tip placement. Variation in these factors could affect the patterns of water flow in the "isolation" impression. Laminar water flow could conceivably produce static warm water areas over the tooth and cause selective removal of fresh cold water from the syringe. Changes in the relative positions of the suction and syringe tips could

cause variation in flow which may cause different cooling rates in the test tooth. To minimize this possible effect, attempts were made in this study to place the tips in the same relative positions on the "isolation" impression from trial to trial. However, clinically this proved difficult to achieve with precision since both the suction and the syringe tip were hand held. The actual effect of this technique variable is unknown. It may also be responsible for some of the previously noted variability between trials. Future researchers using this thermal testing technique may be wiser to provide a means of stabilizing the positions of the syringe and suction tips on the "isolation" impression so that these factors will be constant during all trials.

Recommendations for Future Research

This project has been a pilot study and was done to investigate the feasibility of its methodology as well as the topic of thermal sensitivity as a function of the presence of bases under amalgam restorations. The findings of this study have answered some questions and in turn have caused other questions to be asked. How much base is needed? Will the difference between a based and and unbased amalgam be constant with time? Could this methodology be useful in the investigation of the mechanism of thermal sensitivity? Future research could be directed towards answering these questions using modified forms of this methodology.

How much base is needed? Could a lesser thickness of base accomplish as much practical insulation as the ideal depth base? One laboratory study indicated that 0.6mm is the minimum amount of liner or base necessary to prevent thermal hypersensitivity. Various thicknesses of insulating material could be compared with an "ideal" thickness standard. The thermal testing methodology of this research could be used to conduct clinical trials of thermal sensitivity of "ideally" based amalgam restorations versus other amalgam with lesser thickness of protective insulation.

Are the differences in thermal diffusivity of the various cements significant clinically? The sensory response times of inlays with different types of cement bases (eg. zinc phosphate versus zinc oxide-eugenol cement) could be compared. The results could then be evaluated in terms of relative effectiveness in reducing postoperative thermal sensitivity. Similarly, different metals over bases could be compared. The various casting alloys could be compared with amalgam and with each other.

Will the difference between a based and unbased amalgam be constant with time? Operative techniques produce tooth injury which is usually answered by the deposition of reparative dentin. The formation of this dentin is believed to reduce the thermal sensitivity of teeth. While the results of this study undoubtedly show that bases are

effective in reducing thermal sensitivity in teeth at a one week postoperative period, they may be unnecessary for that purpose after the layer of secondary dentin is deposited. That is, one might expect that the differences in sensory response times between the based and unbased amalgam inlays may be insignificant after a certain longer time period has elapsed. The methodology developed during this research could easily be used to help answer this question.

Finally, can this methodology be used to investigate the mechanism of thermal sensitivity? As mentioned in the literature review, one of the postulated causes of postoperative sensitivity could be pooled fluid underneath a restoration which potentiates the hydrodynamic mechanism of dentinal sensitivity. A modified inlay technique similar to the one used in this project could be used to test this hypothesis.

At the first appointment, no cavity varnish could be applied following preparation. The temporary would simply be applied and the patient excused. Two inlays of a material with the same thermal conductivity of water would be made in the laboratory. One would be the control inlay and would be left whole. The experimental inlay would have some portion of the surface contacting the pulpal and/or axial floor of the inlay adjusted so that when the inlay is seated a space would exist underneath the restoration which would be adjacent to the open dentinal tubules.

At the second appointment the thermal tests can be done in a manner similar to that used in this study. Just before the inlays are seated, distilled water would be introduced into the preparation so that when the inlays are seated, an intimate contact would exist between tooth structure and inlay. Both inlays would be sealed at the occlusal surface as in the present study. The control inlay would have less fluid pooled underneath it than the experimental inlay. However, both would have equal insulating ability. If the hydrodynamic theory is correct, one would expect that the inlay with a larger fluid reservoir underneath would have a more sensitive response than the control inlay.

SUMMARY

The aim of this research was to evaluate the use of cement bases under amalgam restorations as a means of reducing postoperative hypersensitivity to cold. Sensory response times to a 10 C cold water stimulus were measured in 14 mandibular posterior teeth. The teeth had occlusal carious lesions sufficiently deep when excavated to receive a cement base and had no previous restorations.

The experimental procedure consisted of (1) thermal tests prior to anesthesia and tooth preparation to establish the preoperative baseline sensitivity for each patient, (2) preparing each tooth with an inlay type preparation, (3) fabricating an "ideally" based amalgam inlay and a no base amalgam inlay in the laboratory, and (4) on a subsequent appointment (2-7 days later), measuring the patient's sensory response time to the 10 C cold water stimulus applied when each amalgam inlay was in place. Each patient was their own control. Comparisons were evaluated between the preoperative sensory response time and those of the based and nonbased inlays.

Twelve of the fourteen teeth had faster sensory response times in the "no base" tests than in the "with base" tests. The data were analyzed using paired "t" tests. Results revealed that the sensory response times in the "no base" category were significantly shorter than those in the

"with base" category, ($p=0.0071$). In addition, eight patients volunteered that the "no base" thermal tests caused greater pain of longer duration than the "with base" tests.

Comparison between the preoperative thermal tests and the "no base" inlay showed that the "no base" trials had significantly shorter sensory response times ($p=0.0010$). The differences between the "with base" inlay trials and the preoperative sensory response times were not highly significant ($p=0.0940$).

The use of cement bases under amalgam restorations was found to be a practical and effective means of reducing postoperative sensitivity to cold at one week postoperatively.

CONCLUSIONS

Based upon the findings of this study regarding the length of response times to cold stimuli, the following conclusions are made:

1. A tooth restored by an amalgam restoration without a base is significantly more sensitive to cold at one week postoperatively than it was with the untreated caries prior to restoration ($P = 0.0010$).

2. A tooth restored by an amalgam restoration with an "ideal" depth base where indicated is slightly more sensitive to cold at one week postoperatively than it was with the untreated caries prior to restoration. However the difference in sensitivity is not highly significant ($P = 0.0940$).

3. Teeth having amalgam restorations with bases are significantly less sensitive to cold than the same teeth with amalgam restorations without bases ($P = 0.0071$).

4. Cement bases are recommended in teeth being restored with amalgam when the prepared cavity is deeper than is required for mechanical reasons alone.

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SENSIBILITY OF TEETH HAVING BASED VERSUS NON-BASED
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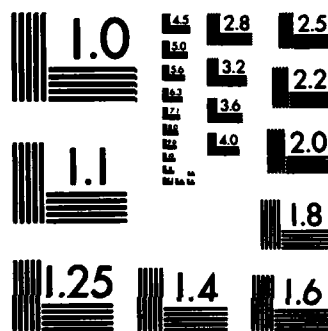
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APPENDICIES

CONSENT FORM



The University of Michigan

SCHOOL OF DENTISTRY

ANN ARBOR, MICHIGAN 48109

As part of a continuing research program in the Department of Operative Dentistry to improve knowledge about the effectiveness of clinical procedures, we are investigating the use of cement bases as thermal insulation underneath amalgam restorations. This study will evaluate the comparative sensitivity of your tooth when based and non-based restorations are used.

Participation in this study requires that you have a mandibular (lower) tooth which has caries (decay) requiring restoration or a defective restoration requiring replacement. Under local anesthesia, the caries (decay) or defective restoration will be removed using standard, accepted dental techniques. The tooth will then receive an interim restoration (temporary filling) to protect the excavated tooth until the next appointment. On the next appointment the interim restoration will be removed without local anesthesia. Care will be taken so that it is removed with minimum or no discomfort. Test restorations will be inserted briefly and tested for thermal sensitivity. The sensitivity will be tested with a stream of cold water flowing over the tooth. The moment you feel the cold water stimulus, the stream of cold water will cease. Due to the nature of this study, some discomfort of a short duration may be expected. When the thermal tests have been completed, you will receive local anesthesia and the tooth will be prepared to receive a final amalgam restoration using standard, accepted dental techniques. No charge will be made for this final amalgam restoration.

I agree to participate in this research study. This study has been explained to me and I understand its purpose and the procedures involved. I have had the opportunity to discuss this project with Dr. Brock Miller and my questions have been satisfactorily answered.

During this study, I consent to the taking of photographs to be used solely for teaching purposes as education material, and for publication in scientific journals.

I understand that I am free to withdraw my consent and to discontinue participation in this project at any time without jeopardizing my eligibility for treatment at this institution.

I understand that The University of Michigan will provide first-aid medical treatment in the unlikely event of physical injury resulting from research procedures. Additional medical treatment will be provided in accordance with the University's determination of its responsibility to do so. The University does not, however, provide compensation to a person who is injured while participating as a subject in research.

 Patient's Signature

 Date

 Witness

 Date

DATA COLLECTION SHEET

Patient Number _____

Date _____

Patient Name _____

Address _____

Telephone _____ Age _____ Sex M/F (circle one)

Appt 1 Tooth # _____ Date _____

Trial 1 2 3 Ave

Time (seconds) _____

Caries present? Yes / No Surface? _____

Prior restoration? Yes / No Surface? _____

Appt 2 Date _____

With Base

Trial 1 2 3 Ave

Time (seconds) _____

No Base

Trial 1 2 3 Ave

Time (seconds) _____

Notes:

END

FILMED

10-83

DTIC